NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

WASHINGTON, D.C

CONTRACTOR FINAL REPORT

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DOT HS-801 739

IMPACT TESTING OF ALLIED CHEMICAL "INFLATABAND" WITH DUMMIES AND HUMAN VOLUNTEERS, VOLUME II

Contract No. DOT-HS-4-00933

October 1975

Final Report

PREPARED FOR:
U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
Washington, D.C. 20590

Document is available to the public through
the National Technical Information Service,
Springfield, Virginia, 22161

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS-801 739		

4. Title and Subtitle
Impact Testing of Allied Chemical "Inflataband" With Dummies and Human Volunteers, Vol. II.

5. Report Date
October 1975

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.

9. Performing Organization Name and Address
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10. Work Unit No.

11. Contract or Grant No.
DOT-HS-4-00933

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
National Highway Traffic Safety Administration 400 Seventh Street S.W.
Washington D.C. 20590

13. Type of Report and Period Covered
Final Report, February 17 to May 16, 1975

14. Sponsoring Agency Code

15. Supplementary Notes
Southwest Research Institute Project No. 11-4020

16. Abstract

The objectives of the testing program were:

(a) evaluate the effectiveness and performance of the "Inflataband" restraint system as a viable method of occupant protection in a simulated head-on automotive crash, and

(b) evaluate the kinematic performance of anthropometric dummies and human volunteers under simulated impact conditions when restrained by the "Inflataband."

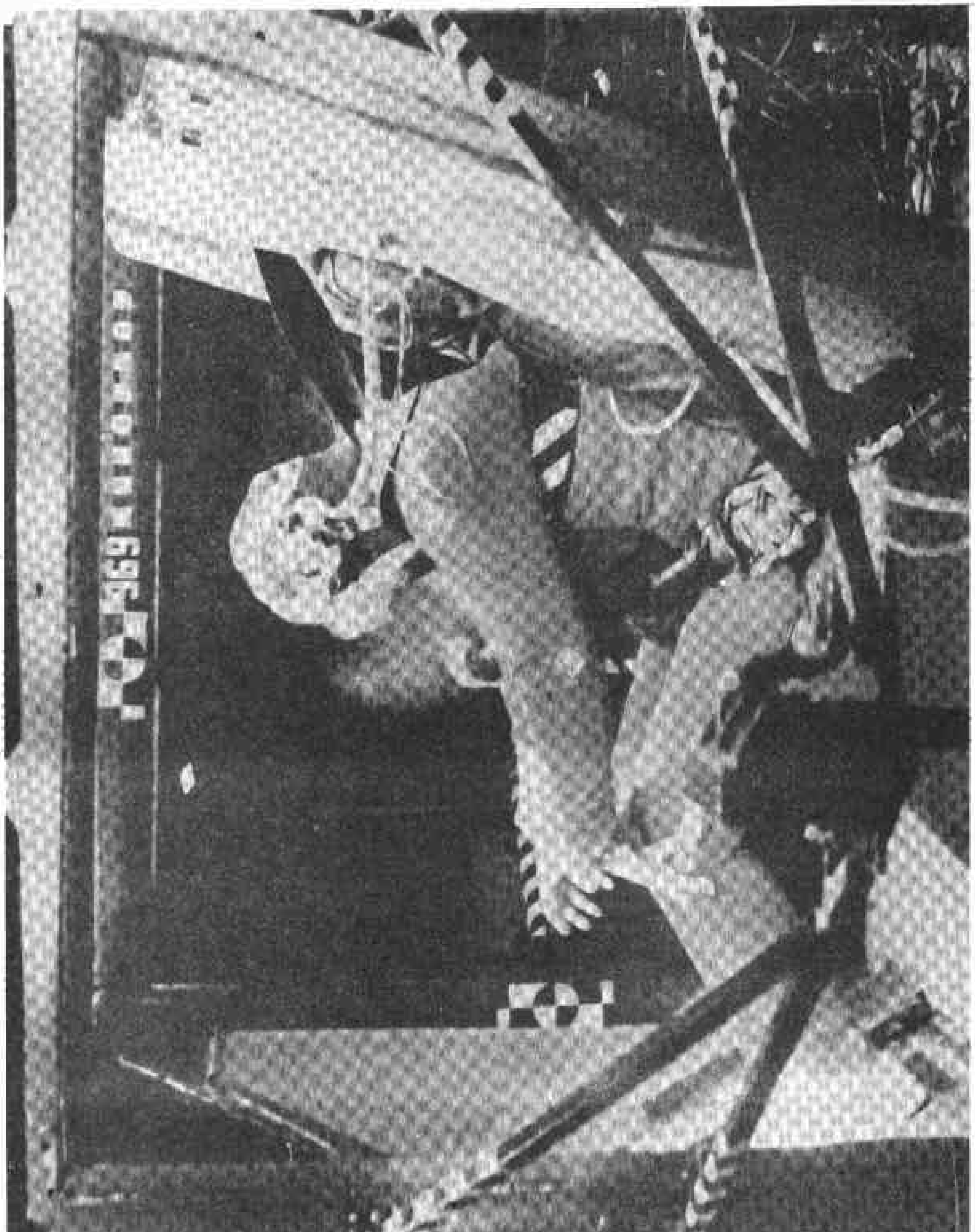
The program formulated to satisfy the objectives consisted of 69 dynamic sled tests (30 dummy tests and 39 human tests). Test results indicate that (1) the "Inflataband" provide~~s~~ acceptable restraint for the impact mode utilized and (2) that the dummy response to impact is more exaggerated than that observed with the human volunteers, but the discrepancies diminish with increasing impact severity.

17. Key Words
Anthropometric dummy, human volunteer, trauma, erythema, ecchymosis

18. Distribution Statement
Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-69)



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I. INTRODUCTION

The objectives of this program as stated in the work statement have been:

1. Evaluate the effectiveness and performance of the "Inflataband" restraint system as a viable method of protecting drivers and passengers involved in the head-on automotive crash environment.

2. Evaluate the kinematic performance of the anthropometric dummies and volunteer human subjects under simulated impact conditions when restrained by the system mentioned above.

In any program involving the use of human volunteers, every effort must be made to ensure the rights and welfare of the subject above and beyond the successful completion of program objectives. To accomplish the task, a test program was designed containing many essential features of previous successful human volunteer programs.

The information contained in this final report describes the test procedures and documents the findings. The text represents the chronological interval of February 21, 1975 to May 16, 1975 and summarizes the results of 69 dynamic sled tests, including 30 dummy tests and 39 human tests.

II. SUMMARY AND CONCLUSIONS

The program was conducted to completion as planned without major incident. In every test, the primary system functioned in a satisfactory manner and displayed the essential characteristics required of an effective restraint system. System activation and restraining forces were accomplished with minimal expenditure of time. As witnessed by the absence of significant trauma in the human volunteers, impact loads were effectively distributed over the chest and abdomen. Occupant kinematics were controlled by the system in such a manner that tendencies to submarine were minimal, and the displacements of vulnerable body elements were within the interior constraints of the vehicle simulated.

Injuries to the human subjects consisted primarily of mild erythema to the face and neck; at the higher impact severities, some residual neck soreness was documented in the post-impact evaluation forms completed by the volunteers. In terms of existing human tolerance criteria (head severity index - HSI, chest severity index - CSI and head injury criterion - HIC) and observed injury, the Inflataband™ provided effective occupant restraint in simulated head-on collisions for which the total velocity change was equivalent to a 30 mph barrier collision; however, conditions were so precisely controlled that the results represent the best possible situation which in reality may rarely exist. The influence of such variables as occupant physical condition, age, size, pre-impact position, muscle tone at impact, impact direction, etc. cannot be overemphasized. It must also be recognized that the system as tested was purely a prototype and was not without operational problems as observed during the program. To be a production item, modification will be required.

When comparing the results of dummy tests with the results of human tests, the first notable discrepancy occurred in the kinematic response to impact. Because of the presence of muscle tone, the typical human response to impact was more subdued than that of the dummy. The test results (HSI, CSI, HIC, belt loads) for the low and intermediate impact severities indicate that the anthropometric dummies' responses to impact were conservative estimates of human response; however, at the higher levels (31 mph/49.9 kph sled total Δv), the dummy and human severity indicators converged to similar values indicating a potential threshold (for the system tested) above which muscle tone may not be as significant as at the lower impact severities.

III. EVALUATION PROGRAM

A. Program Plan

The program as conducted at SwRI was divided into three (3) phases. The first phase consisted of the review of system testing results with dummies conducted at NADC, Philadelphia and a design review of the Inflataband™. Prior to the first human test, all pressure components were proof tested to 10,000 psi (7031 kgs/mm^2). Critical load carrying components were tested to failure on tensile testing machines to document strength characteristics. These initial efforts were followed by sled tests for the purpose of qualifying the system for human testing. Dummy tests using three (3) dummy types (5th percentile female, 50th percentile male, and 95th percentile male) were conducted at a nominal total velocity change of 32.5 mph (52.3 kph) and peak sled deceleration of 20 g's. Test results were carefully reviewed in order to ascertain potential hazards and operational problems.

The second phase was devoted to volunteer selection and indoctrination. In order to satisfy the doctrine of informed consent, all medically approved volunteers were given the opportunity to view the high speed film of a representative dummy test and experience a dynamic test (with deployment) at a nominal 8.5 mph (13.7 kph) sled velocity change.

The third phase, denoted as production testing, incorporated the stepped-severity technique in which human subjects are exposed to increasingly severe impact environments. Beginning at 12.5 mph, (20.1 kph), tests were conducted at nine different impact severity levels, each step being 2.5 mph (4.0 kph) greater in velocity change than the previous step. Each test series contained five (5) tests; the first two tests were conducted with anthropometric dummies followed by three (3) human tests. A test summary is presented in Table 1.

B. Impact Simulator

The impact simulator utilized in the sled impact tests was an impact/rebounding type, MTS Model 858.05 with modifications by SwRI. Propulsion is provided by natural-rubber bungee cords, and the deceleration pulse is generated as the sled (traveling at a specified velocity) impacts the pneumatic programmer. The impact of the sled compresses a gas volume/s until the kinetic energy of the sled is absorbed. At this point, the potential energy stored in the compressed gas volume/s is released as the gas expands accelerating the sled on the rebound stroke. After losing contact with the programmer, the sled is slowed by the

Table 1

Summary of Test Runs

Test No.	Date	Sled Δ v mph (kph)	Subject	Remarks
837	2/21/75	32.4 (52.2)	50th ATD	Qualification Test
840	3/6/75	30.6 (49.3)	95th ATD	Secondary Restraint Test
841	3/7/75	32.6 (52.5)	50th ATD	Qualification Test
842	3/10/75	32.6 (52.5)	50th ATD	"
843	3/11/75	33.2 (53.5)	50th ATD	"
845	3/12/75	34.1 (54.9)	5th ATD	"
851	3/13/75	10.3 (16.6)	50th ATD	Preliminary Test
852	3/13/75	10.9 (17.5)	95th ATD	"
853	3/14/75	00.0 (00.0)	SwRI Staff	Static Sled/Dynamic Deployment
854	3/14/75	9.8 (15.8)	No. 42	Indoctrination Test
856	3/17/75	10.2 (16.4)	No. 1	"
857	3/18/75	10.1 (16.3)	No. 16	"
858	3/19/75	9.9 (15.9)	No. 40	"
859	3/19/75	9.9 (15.9)	No. 21	"
860	3/20/75	10.1 (16.3)	No. 24	"
861	3/20/75	32.6 (52.5)	50th ATD	Qualification Test
862	3/21/75	33.3 (53.6)	5th ATD	"
863	3/24/75	31.4 (50.6)	50th ATD	"
864	3/25/75	32.1 (51.7)	50th ATD	"
865	3/25/75	9.5 (15.3)	No. 33	Indoctrination Test
866	3/26/75	10.0 (16.1)	No. 13	"
867	3/27/75	10.0 (16.1)	No. 28	"
868	3/31/75	10.1 (16.3)	No. 35	"
871	4/1/75	10.3 (16.6)	No. 36	"
872	4/1/75	10.3 (16.6)	No. 41	"
881	4/4/75	13.5 (21.7)	50th ATD	Production Test
882	4/4/75	13.2 (21.3)	95th ATD	"
884	4/7/75	12.3 (19.8)	No. 16	"
886	4/8/75	12.3 (19.8)	No. 36	"
887	4/8/75	12.2 (19.6)	No. 33	"
895	4/9/75	15.2 (24.5)	50th ATD	"
897	4/10/75	14.8 (23.8)	95th ATD	"
898	4/10/75	14.9 (24.0)	No. 1	"
900	4/11/75	15.0 (24.2)	No. 42	"
901	4/11/75	14.9 (24.0)	No. 41	"
906	4/14/75	17.9 (28.8)	50th ATD	"
908	4/15/75	17.4 (28.0)	95th ATD	"
909	4/15/75	17.7 (28.5)	No. 13	"
913	4/17/75	17.6 (28.3)	No. 21	"
914	4/17/75	17.5 (28.2)	No. 40	"

Table 1 (Cont'd)

Test No.	Date	Sled Δv mph (kph)	Subject	Remarks
918	4/18/75	20.5 (33.0)	50th ATD	Production Test
920	4/21/75	20.2 (32.5)	95th ATD	"
922	4/22/75	20.5 (33.0)	No. 28	"
924	4/24/75	20.5 (33.0)	No. 24	"
925	4/24/75	20.8 (33.5)	No. 35	"
929	4/28/75	- (-)	50th ATD	"
931	4/29/75	22.1 (35.6)	95th ATD	"
932	4/29/75	22.4 (36.1)	No. 13	"
934	4/30/75	- (-)	No. 1	"
937	4/30/75	22.1 (35.6)	No. 21	"
940	5/1/75	25.2 (40.6)	50th ATD	"
942	5/2/75	24.3 (39.1)	95th ATD	"
943	5/2/75	24.4 (39.3)	No. 41	"
945	5/5/75	24.3 (39.1)	No. 40	"
946	5/5/75	25.1 (40.4)	No. 16	"
952	5/6/75	27.5 (44.3)	50th ATD	"
954	5/7/75	27.1 (43.6)	95th ATD	"
955	5/7/75	27.1 (43.6)	No. 24	"
957	5/8/75	28.2 (45.4)	No. 35	"
958	5/8/75	27.6 (44.4)	No. 28	"
963	5/9/75	30.8 (49.6)	50th ATD	"
965	5/12/75	29.7 (47.8)	95th ATD	"
966	5/12/75	30.2 (48.6)	No. 16	"
968	5/13/75	29.3 (47.2)	No. 40	"
969	5/13/75	29.3 (47.2)	No. 1	"
973	5/14/75	32.9 (53.0)	50th ATD	"
975	5/15/75	32.0 (51.5)	95th ATD	"
976	5/15/75	32.3 (52.0)	No. 13	"
978	5/16/75	32.3 (52.0)	No. 24	"
979	5/16/75	32.1 (51.7)	No. 28	"

stretching of the bungee cords. At a predetermined location on rebound, the sled brakes are actuated effecting a complete stop.

C. Deceleration Pulse

The deceleration pulse utilized for the 32.5 mph (52.3 kph) total velocity change tests, Figure 1, was a SwRI approximation of a representative 30 mph (48.3 kph) barrier crash pulse for a 1972 Pinto. Although there was no attempt to do so, the SwRI pulse compared closely with the crash pulse used by Allied Chemical in a previous testing series conducted at their facility. The deceleration pulses used for the lower severity levels were scaled from the 32.5 mph (52.3 kph) pulse. Table 2 summarizes the peak sled parameters as scaled from the 32.5 mph (52.3 kph) pulse.

D. Sled Buck

The sled buck used in the program was designed by SwRI to simulate the essential features of the RFP (right front passenger) compartment of a 1972 Pinto. Restraint system anchor points (with respect to seat anchor points) were patterned after those used at NADC. The test set-up included a production, 1972 Pinto seat, a special head restraint, and seat ramp (Figure 2). Seat adjustment fore and aft was made to accommodate the anthropometrics of the volunteers. Figure 3 depicts in schematic form the attachment points, seat anchor points, etc. The buck had no provisions for simulated instrument panel or windshield.

E. Primary Restraint System

The Inflataband™, Figure 4, as used in the test program is an inflatable three-point harness system with lap and over the shoulder components. Four major assemblies, Figure 5, comprise the system: the inflator, the buckle, the tongue and manifold and the band (including both lap and shoulder portions). Inflation is provided by a pressurized gas cylinder housing two electroexplosive devices (squibs). When an impact condition is detected, an electrical signal is generated activating the squibs. Squib activation creates sufficient overpressure of the stored Argon gas in the inflator to rupture a disc permitting the gas to flow through the ports in the buckle assembly into the lap and shoulder segments. The rubber inlet tubes, attached to the manifold assembly, direct the gas into the fabric portions of the band segments. At full inflation, the shoulder and lap band segments are approximately 18 inches (45.7 cm) in circumference.

The system operation with an anthropometric dummy in a simulated crash situation is illustrated in Figure 6. Figure 6a shows the initial condition as the sled first contacts the programmer (denoted as time zero). A predetermined delay of 10 millisec occurs next in which nothing happens.

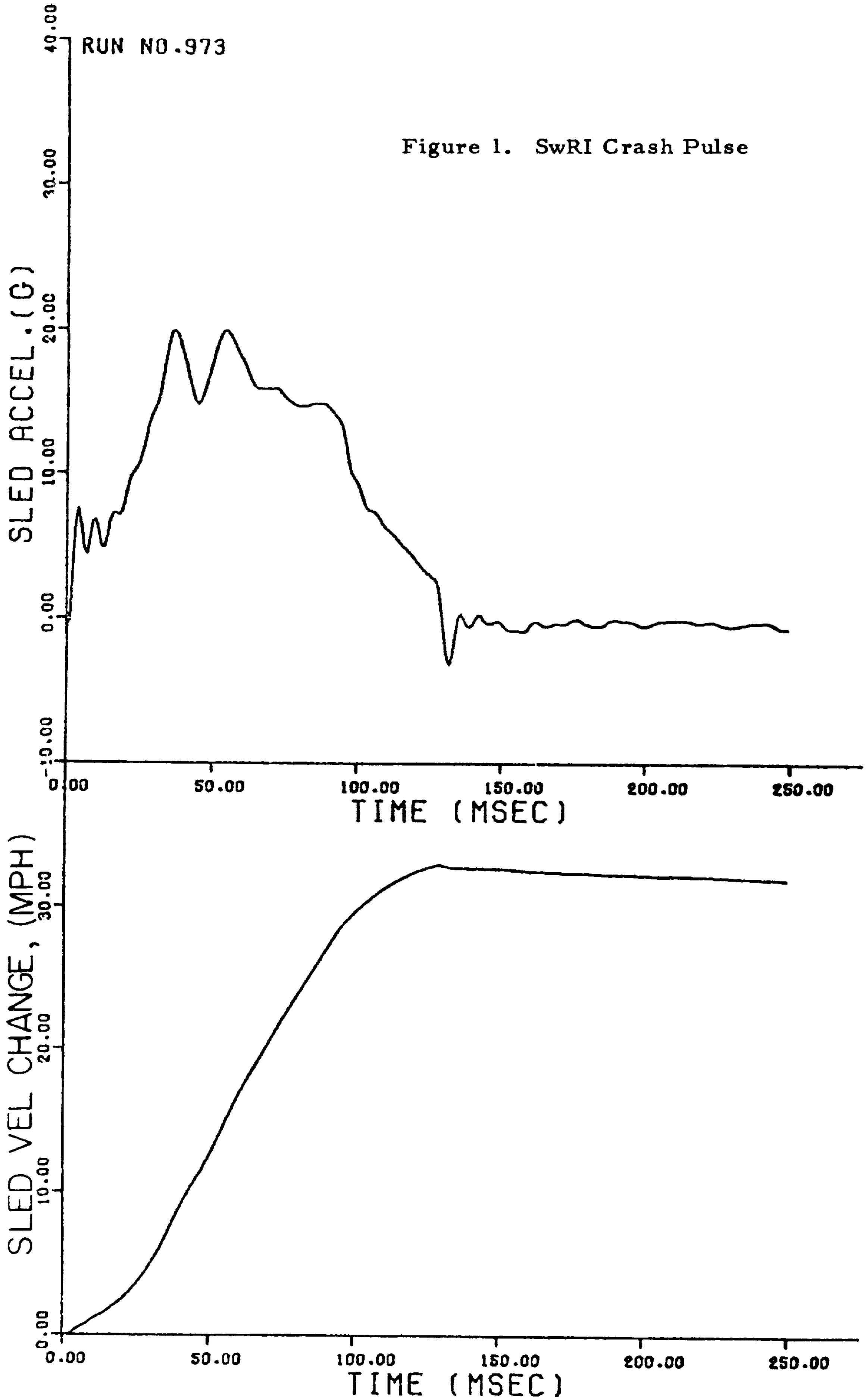


Figure 1. SwRI Crash Pulse

Table 2

Production Test Parameters (Nominal Values)

Sled Velocity Change mph (kph)	Sled Peak Deceleration g's
12.5 (20.1)	7.5
15.0 (24.2)	9.0
17.5 (28.2)	10.5
20.0 (32.2)	12.0
22.5 (36.2)	13.5
25.0 (40.3)	15.5
27.5 (44.3)	17.0
30.0 (48.3)	18.5
32.5 (52.3)	20.0

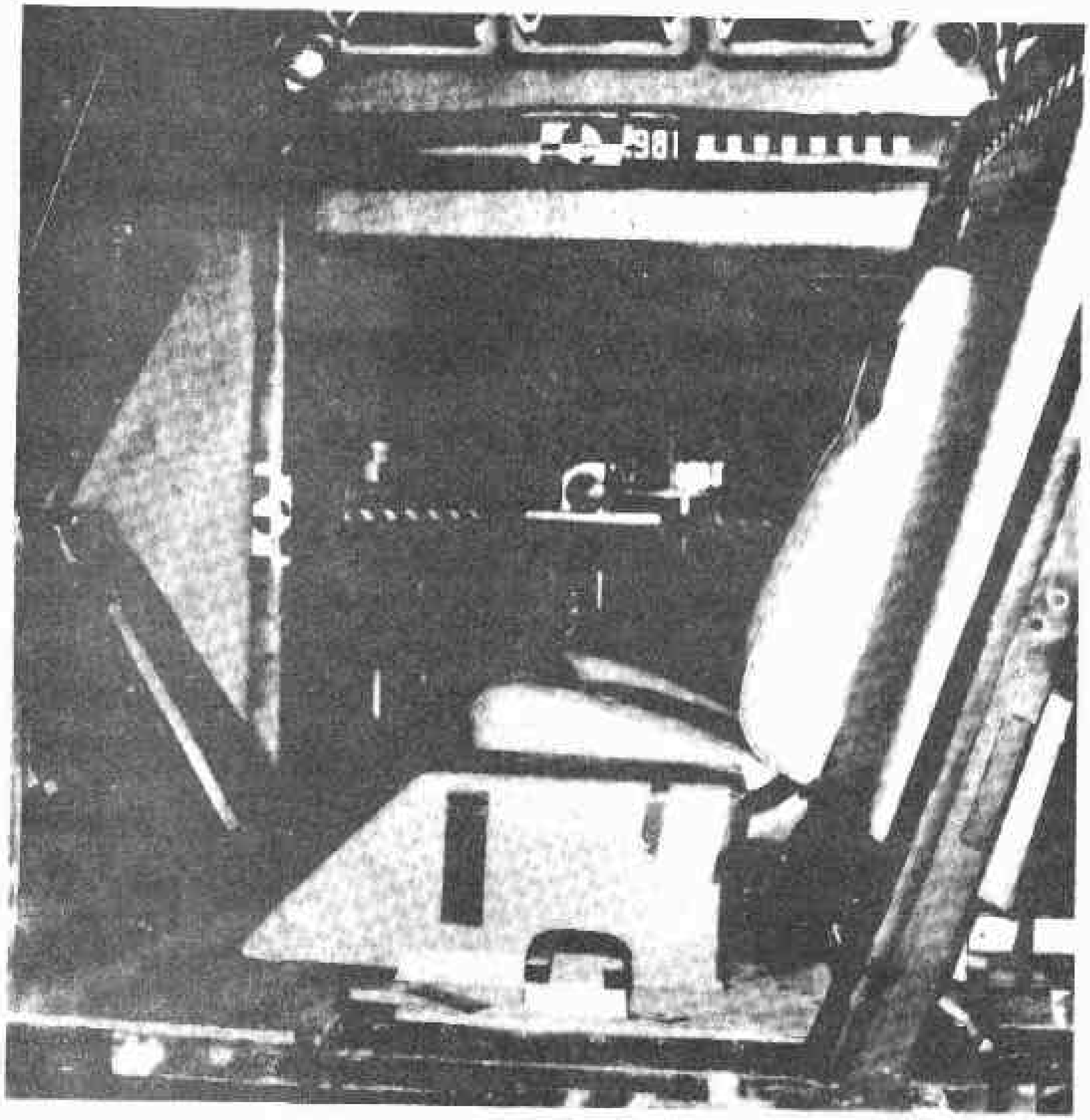


FIGURE 2. SLED TEST BUCK

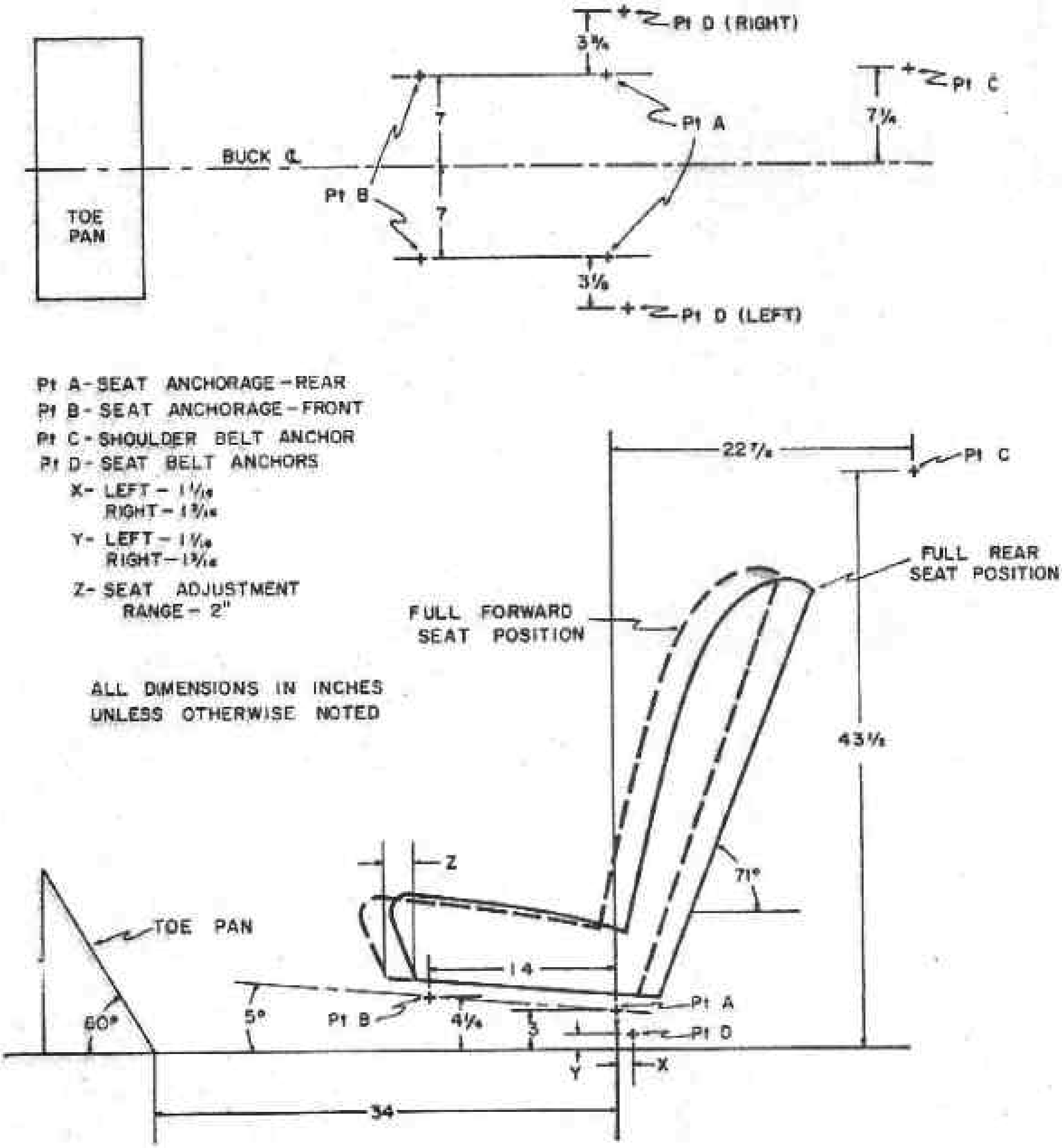


Figure 3. Buck Attachment Points

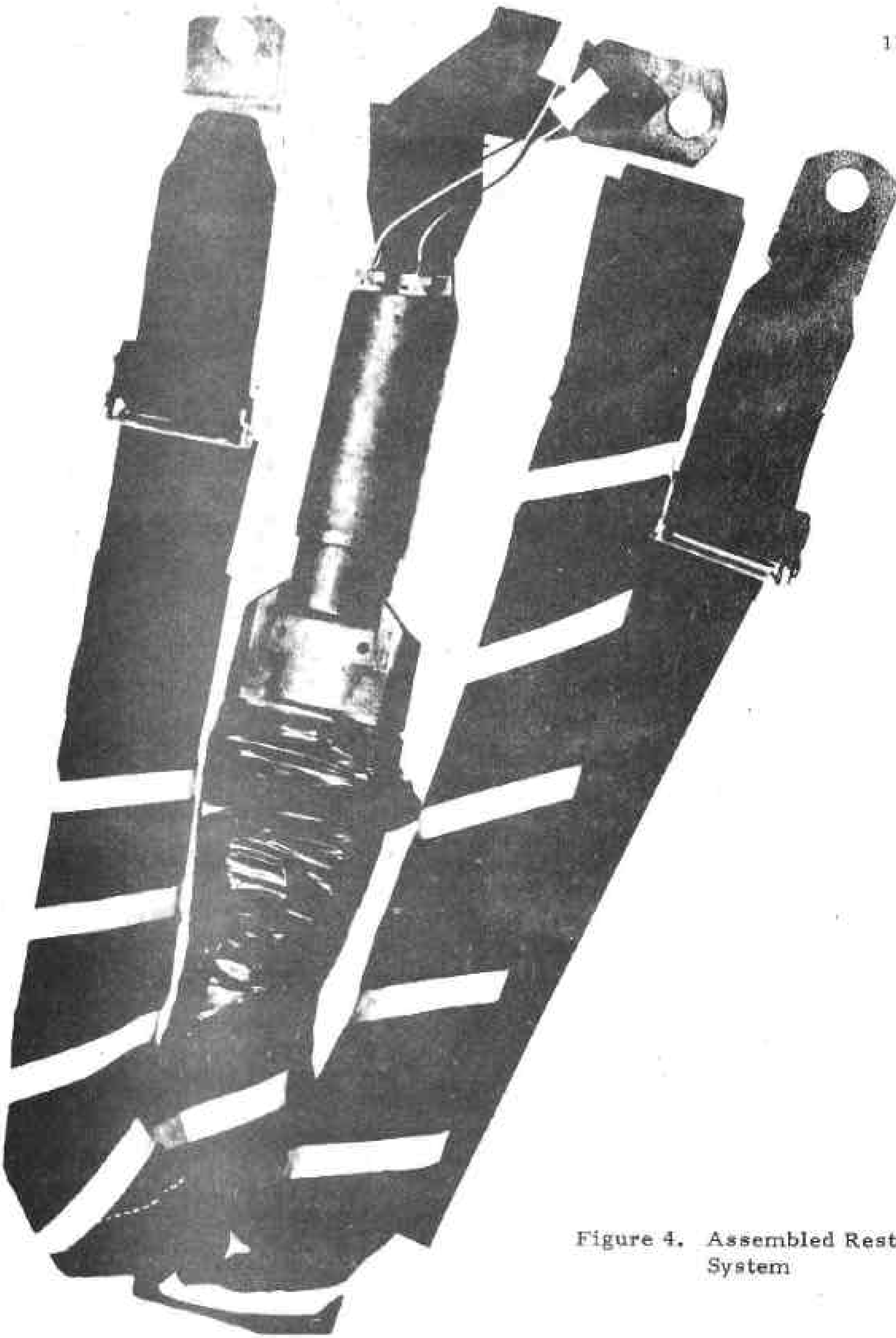


Figure 4. Assembled Restraint System

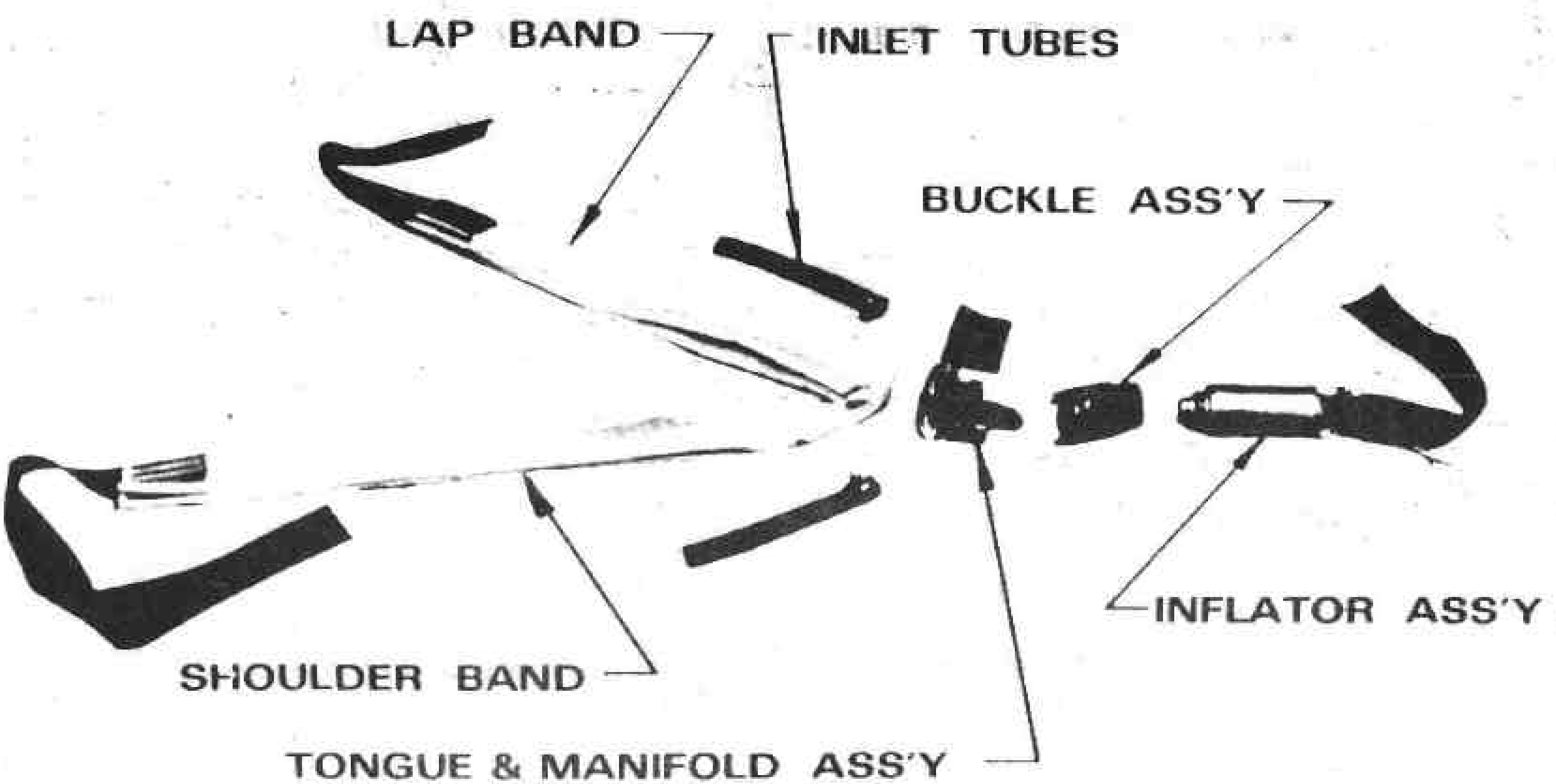


Figure 5. Restraint System Components

INFLATABAND SYSTEM (INFLATABUCKLE) - EXPLODED VIEW

Figure 6a. Impact, t = 0

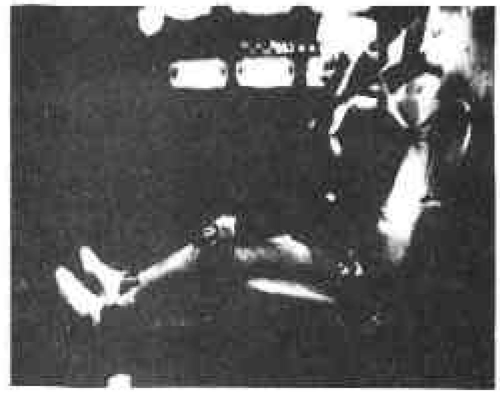


Figure 6b. Deployment, t = 10 msec

Figure 6c. Full Inflation, t = 17 msec

Figure 6d. Max. Head Acc.
t = 87 msec

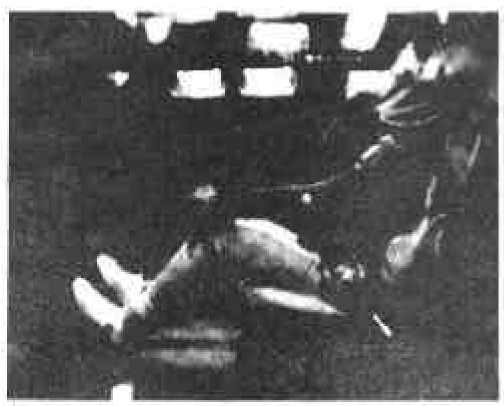


Figure 6e. Rebound, t = 194 msec

Figure 6. System Operation

Figure 6b shows the situation 10 millisec after initial contact. At this point in time, the electrical signal required to activate the squibs is generated by a switch closure. In a normal situation, a crash sensor in the vehicle would transmit an electrical signal to the gas generator; however, as the testing of sensors was not an objective of the test program, a redundant activation system (for safety to human volunteers) activated by two proximity switches mounted next to the sled rails was used to simulate the sensor. The two circuits were independent and either one could deploy the system. A detailed description of the circuitry is available in Appendix A. In each production test, the proximity switches were positioned to provide a 10 millisec time delay. After 20 millisec from initial contact, the system has inflated (Figure 6c) and is ready to distribute and transmit the occupant load. In Figure 6d, the occupant has attained maximum impact head acceleration. At 194 millisec, the deceleration pulse has been completed. A major portion of the occupant's energy has been dissipated by the frictional flow of the gasses through the weave of the band material. That portion of the occupant's energy stored in the system causes the occupant to rebound rearward into the seat, Figure 6e. The hands of the dummies, as shown in Figure 6, were taped to the knees in an effort to obtain better kinematic correspondence between the human and dummy occupants.

F. Secondary Restraint System

To provide backup restraint in the event the occupant was not effectively restrained by the primary system, several safety precautions were taken. A secondary restraint for backup protection was a belt harness (Figure 7) that restrained the shoulders, chest, lap, and legs in the event the subject was for any reason unrestrained. The harness terminated with an energy absorbing, load limiting device mounted behind the seat of the buck, Figure 8. To avoid any interaction between occupant and secondary restraint in the normal test mode, a given amount of slack (as determined from a dummy test) was introduced into the secondary restraint. During the program, a load cell sensitive to secondary restraint total load was continually monitored.

In addition to the secondary restraint, foam padding and safety netting were used to minimize the possibility of rigid object contact or ejection. Rebound protection was provided by a full head restraint fabricated from Ensolite foam backed with styrofoam. The head restraint had a latent purpose in that it also prevented extreme seat back deflection on occupant rebound.

G. Medical Contingencies

During the human volunteer portion of the program, a board qualified and practicing surgeon was in constant attendance to monitor ECG, blood pressure, pulse rate, and respiration. In the event of injury, the physician was prepared to institute immediate resuscitation and/or

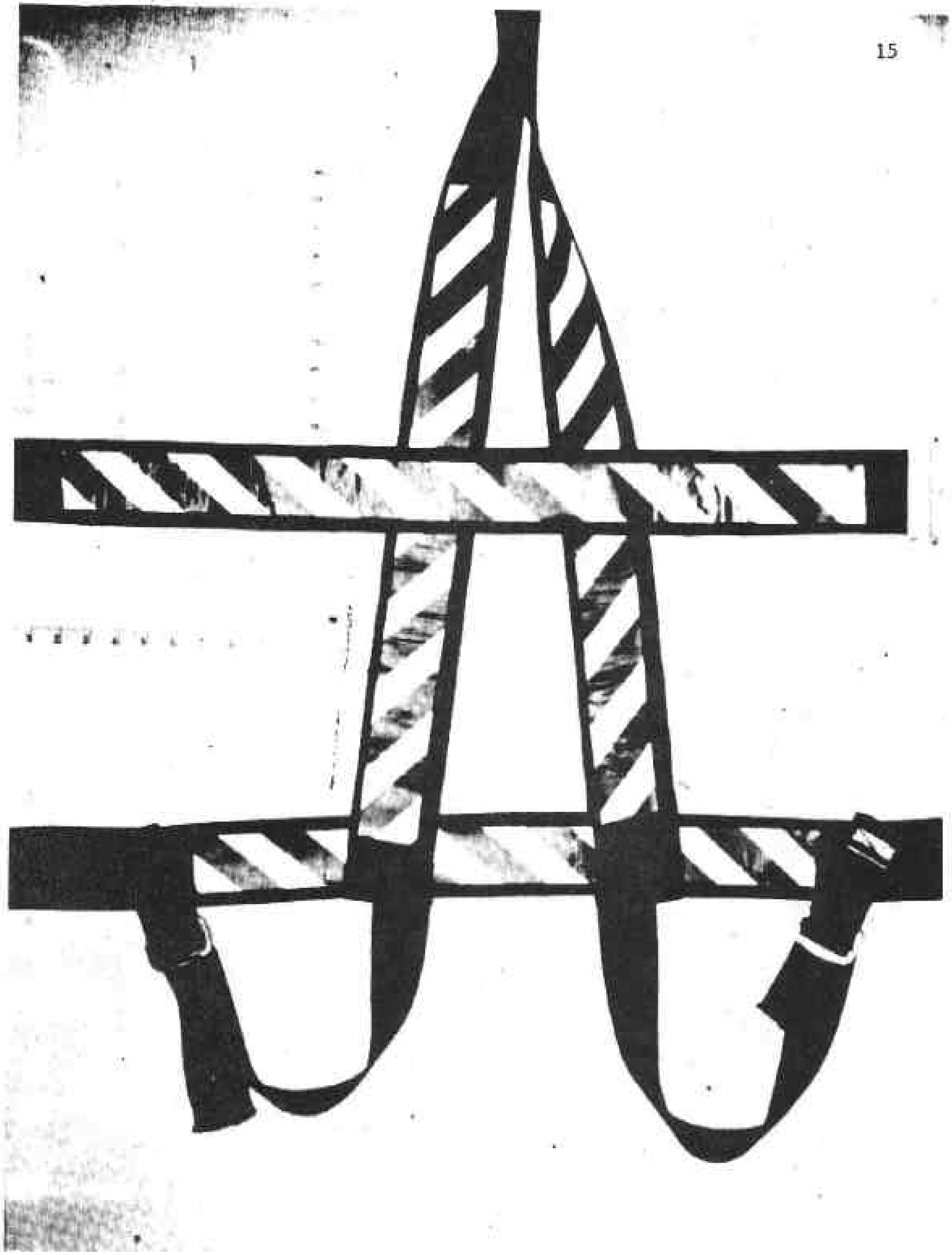


Figure 7. Secondary Restraint Harness

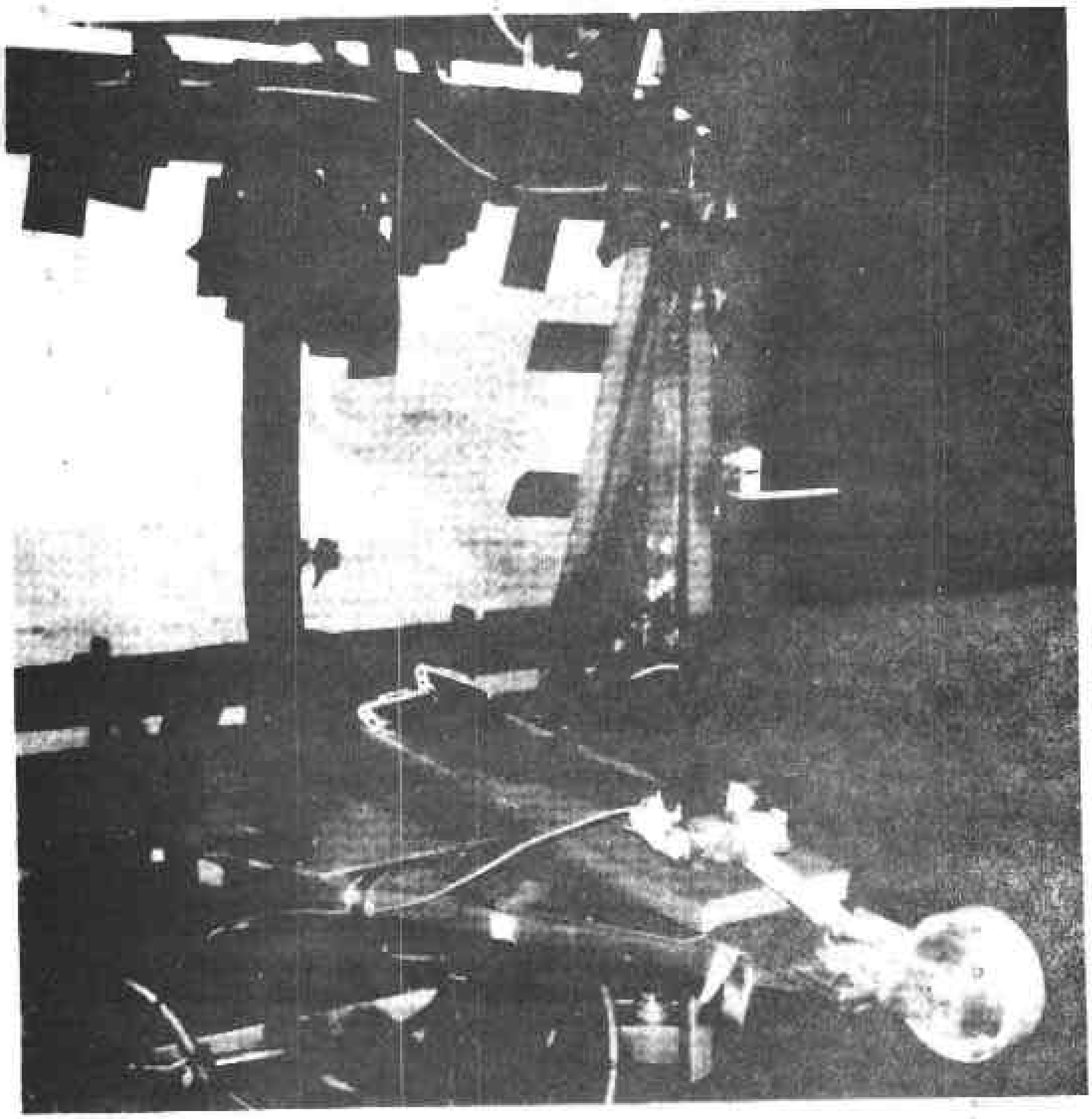


FIGURE 8. ENERGY ABSORBER FOR SECONDARY RESTRAINT

inaugurate first aid treatment. A resuscitator with O_2, a cardiac defibrillator, tracheotomy set, splints, suture sets, I.V. fluids, and drugs were on hand for immediate use. An ambulance with litter was available adjacent to the impact laboratory so that an injured subject could be transported without delay to the nearest treatment center. During the higher level impact tests, the surgeon was joined by a practicing cardiologist.

H. Instrumentation

The instrumentation requirements for the program are summarized in Table 3. The only parameter not measured during the impact sequence was occupant blood pressure. The remaining parameters, as measured by on-board transducers, were transmitted to recording equipment via an umbilical cable. Transducer signals were recorded broadband on companion multichannel analog tape recorders. Event synchronization between machines was provided by a time zero reference level on both tapes as well as a time channel which changed frequency at time zero (1000 Hz to 100 Hz).

Because of the importance of the dummy test results in the "go" or "no go" for human testing at a given impact severity, the instrumentation mounting techniques were the same for dummies as for humans. The head pack accelerometer cluster, shown in Figure 9, was mounted on the left side of an adjustable plastic headband removed from a protective headgear, Figure 10. Preliminary tests indicated that the head pack mounted on the left side of the occupant's head provided maximum isolation of the accelerometers from the ringing produced by the deploying shoulder band. To preclude contact with the subject, an Ensolite pad was secured over the metallic mounting plate.

To measure the acceleration of the thorax, a triaxial accelerometer was mounted on an aluminum plate housed in an Ensolite pad, Figure 11. The accelerometer was positioned over the right erector spinal muscle of the back at the level of T6 vertebra and offset from the mid sagittal plane to prevent injury to any protruding spinous process. To secure the back pack to the subject, a belt of Velcro was fastened tightly around the subject's chest as he exhaled deeply. Over the Velcro strap, the chest belt of the secondary harness was tightened providing additional security.

The anthropometric test dummies (ATD) used in the program were supplied as GFE and consisted of two 50th percentile male dummies, one 95th percentile dummy, and one 5th percentile female. The 50th percentile dummies were manufactured by Humanoid System as part number 572. The 95th percentile dummy was manufactured by Alderson Research in accordance with NHTSA purchase specifications and designated as VIP-95. The Humanoid and Alderson dummies were received new, direct from the

Table 3

Transducer Measurements

Parameter	Manufacturer	Range	Calibration Value
Chest Accel., gx	Entran Devices	500 g	200 g
Chest Accel., gy	" "	"	"
Chest Accel., gz	" "	"	"
Head Accel., 1gx	" "	"	"
Head Accel., 1gy	" "	"	"
Head Accel., 1gz	" "	"	"
Head Accel., 2gy	" "	"	"
Head Accel., 2gz	" "	"	"
Head Accel., 3gy	" "	"	"
Sled Accel.	CEC	100 g	50 g
CG Accel.	"	"	"
Belt Load, Shoulder	Lebow	3500 lbf	2000 lbf
Belt Load, Lap Left	"	"	"
Belt Load, Lap Right	"	"	"
Generator Pressure	Viatran	15000 psi	10000 psi
Toe Pan Right X	SwRI		900 lbf
Toe Pan Right Y	"		1200 lbf
Toe Pan Left X	"		820 lbf
Toe Pan Left Y	"		1800 lbf
Secondary Restraint	"		2000 lbf
Sled Velocity	"		50 ft/sec
EKG			N/A
Respiration			N/A

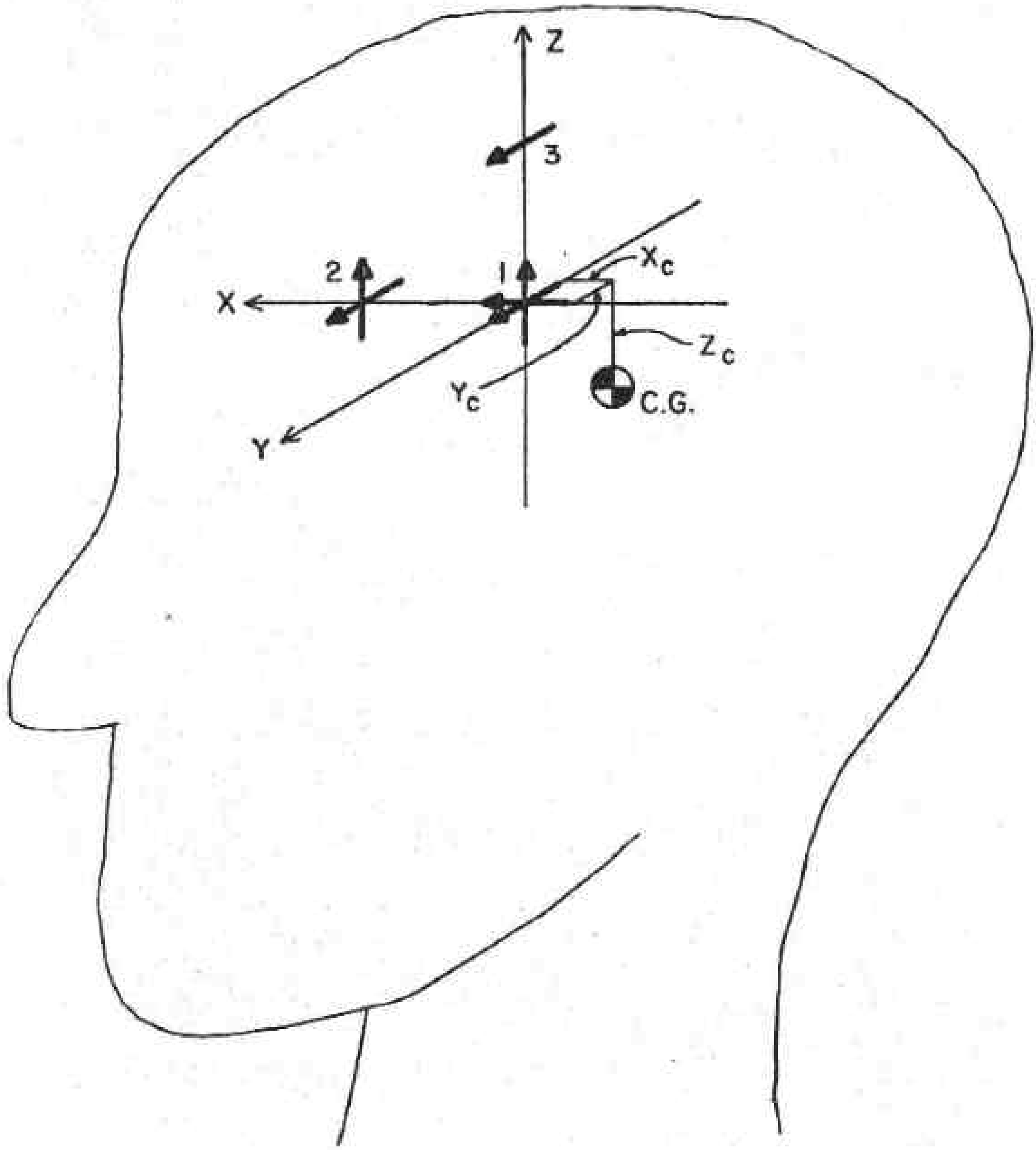


Figure 9. Head Accelerometer Cluster - Identification and Orientation (not to scale)

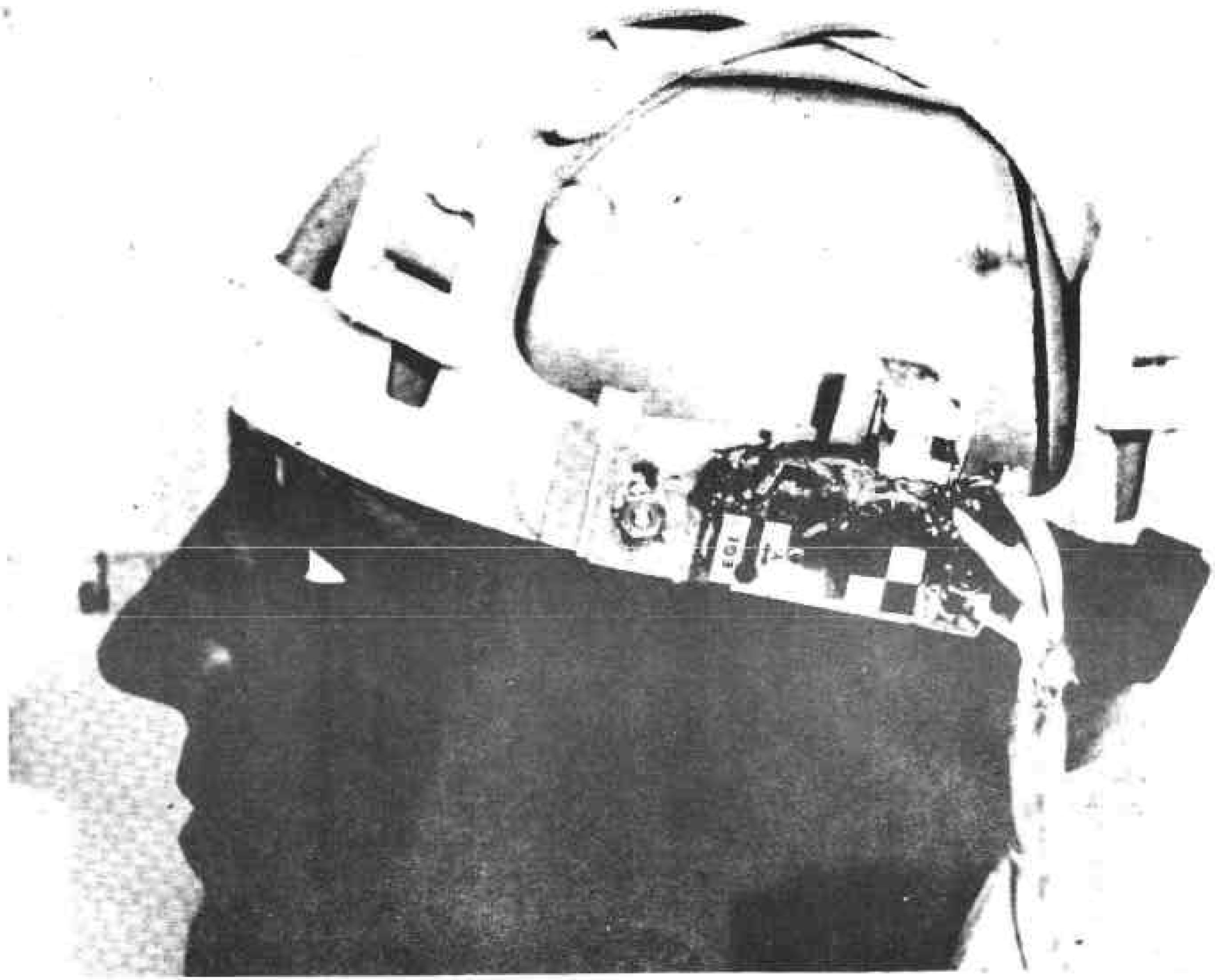


Figure 10. Head Accelerometer
Cluster Harness

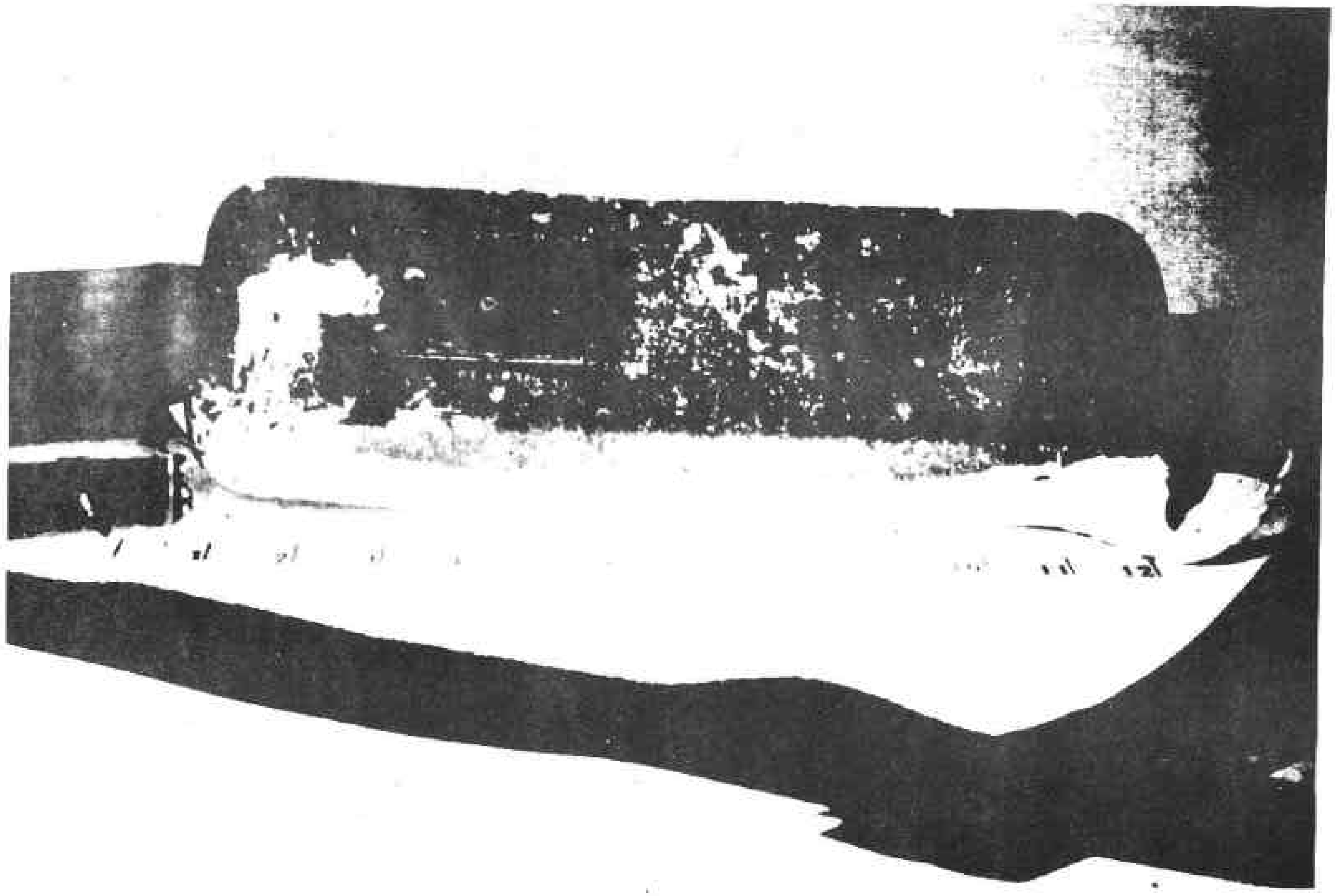


Figure 11. Chest Accelerometer Pack

respective vendor. The female dummy was manufactured by Sierra as part number 592-805 and reconditioned prior to testing.

A complement of internal accelerometers for the dummies was not available until late in the program. Earlier efforts with accelerometers, of questionable condition, were installed for two tests in order to generate internal head acceleration data comparative with externally derived data. For two of three channels, correlation was acceptable. The third channel of the device was suspicioned to be faulty.

The kinematic response of the occupant was photographed from four (4) views with high speed 16mm cameras operating at 850 frames per second or higher. The processed film was available within 12 to 24 hours of the test at which time it was carefully reviewed Figures 12 through 16 are sequence photographs taken from the left side camera film records for the 32.5 mph (52.3 kph) series.

To accentuate the motion of body elements and provide information in regard to subject/restraint system interaction, target data (as specified in SAE J138) were placed at the wrists, elbows (lateral epicondyles), shoulders, ankles (lateral malleoli), knees, and greater trochanters. Targets were placed over each temporoparietal region of the head to help evaluate head motion as recorded on the high speed color movies made of each production test.

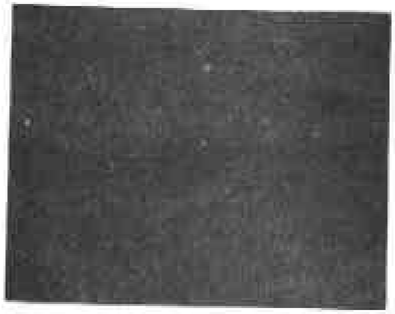
To determine the effects of passenger Inflataband™ deployment upon human volunteer test subjects, and to insure the physical well-being of each subject before, during, and after deployment, medical instrumentation was utilized to acquire vital parameters.

Electrocardiogram (ECG) - An electrocardiogram was performed on all subjects from 12 seconds before sled release until a medically acceptable tracing was achieved after the test run. This varied from one individual to another and is covered in the clinical section of the report. A single stage preamplifier, with a gain of 100 provided good noise-free tracings. The 3-volt batteries limited current to the amplifier to just slightly more than 100 nanoamperes (10^{-7}) to insure subject safety.

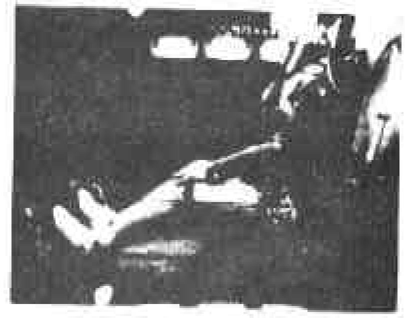
Beckman Ag/AgCl shielded electrodes were used to acquire the signal and were connected to acquire a lead 1 ECG tracing. Coaxial cables insured a noise-free signal to the recording systems.

Lead extenders provided the necessary slack for subject movement during impact. Few tracings were lost as a result of lead breakage, despite rapid decelerative movement of subjects.

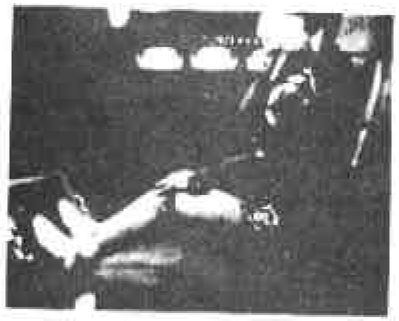
Blood Pressure - Blood pressure was recorded before and after each run by an Arteriosonde® (Roch) Model 1216. The cuff was placed



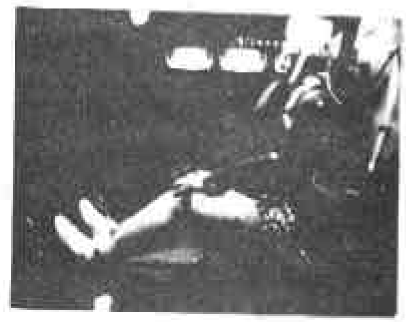
12a. t = 0 msec



12b. t = 7 msec



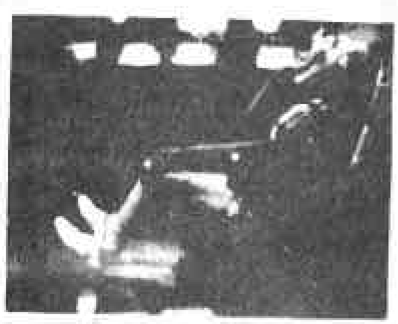
12c. t = 11 msec



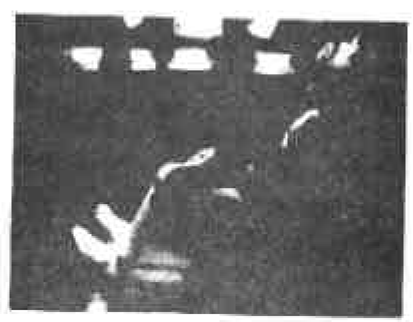
12d. t = 21 msec

12e. t = 37 msec

12f. t = 119 msec



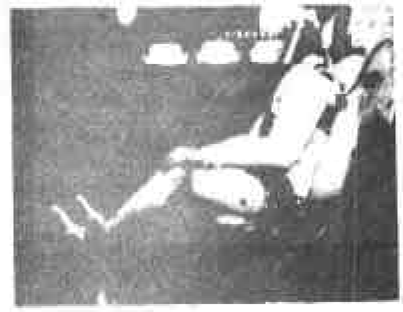
12g. t = 201 msec



12h. t = 221 msec

Figure 12. Occupant Response, Run No. 973

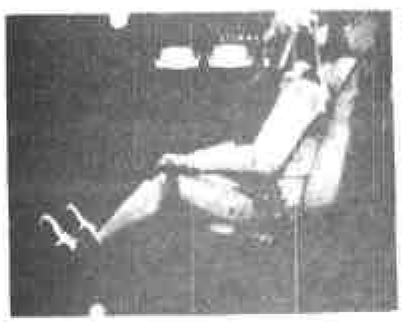
13a. t = 0 msec



13b. t = 12

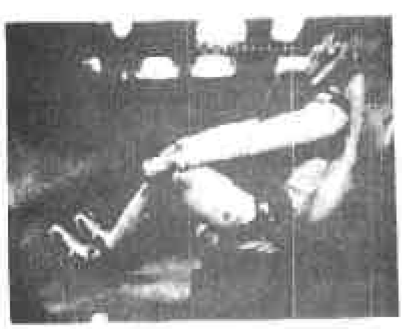
13c. t = 17 msec

13d. t = 77 msec



13e. t = 36 msec

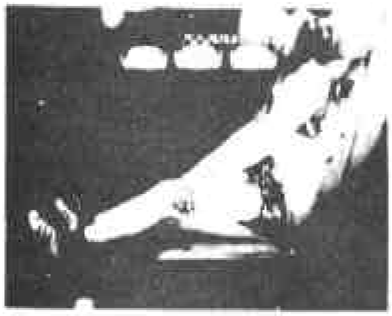
13f. t = 114 msec



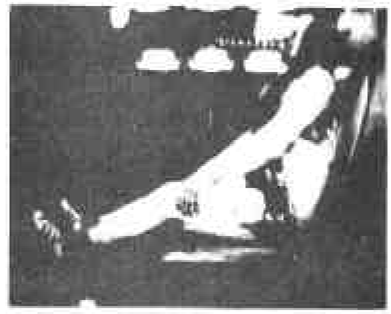
13g. t = 191 msec

13h. t = 244 msec

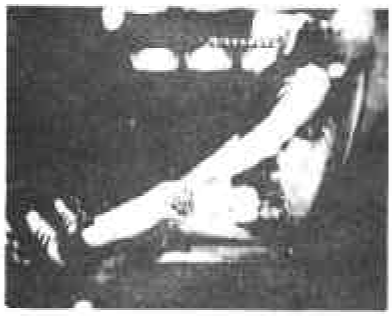
Figure 13. Occupant Response, Run No. 975



14a. t = 0 msec



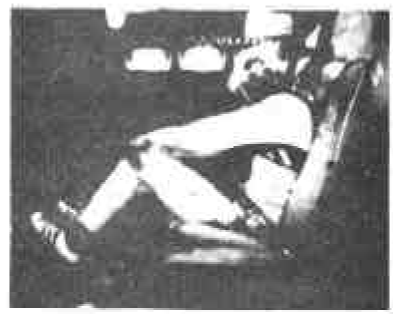
14b. t = 10 msec



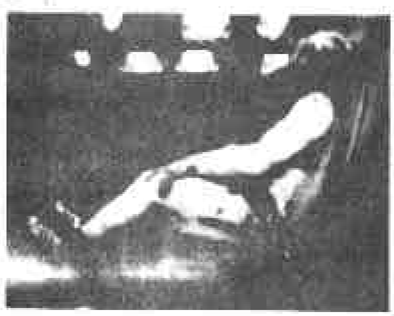
14c. t = 14 msec

14d. t = 79 msec

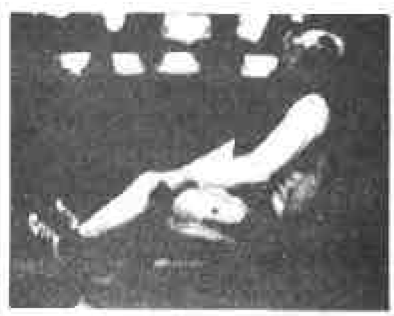
14e. t = 54 msec



14f. t = 124 msec



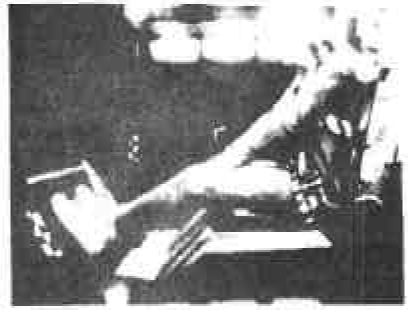
14g. t = 193 msec



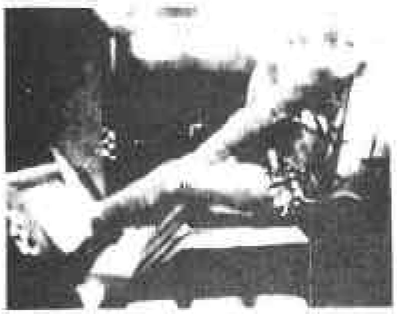
14h. t = 216 msec

Figure 14. Occupant Response, Run No. 976

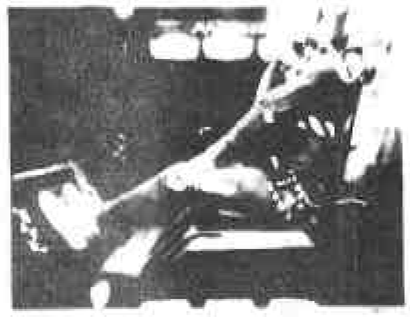
15a. t = 0 msec



15b. t = 8 msec



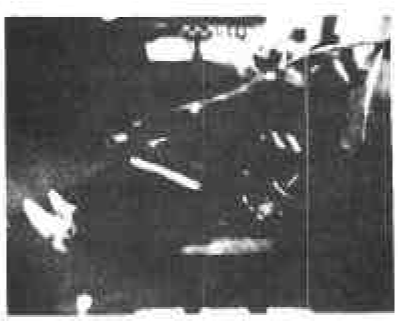
15c. t = 16 msec



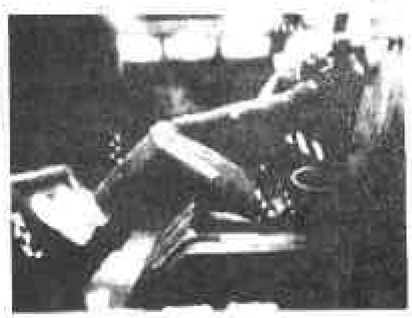
15d. t = 20 msec

15e. t = 49 msec

15f. t = 54 msec



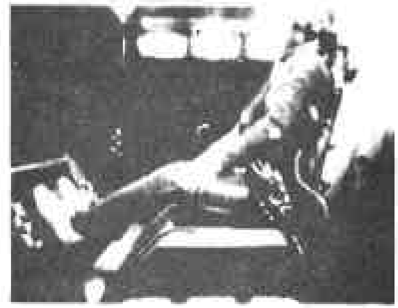
15g. t = 84 msec



15h. t = 142 msec

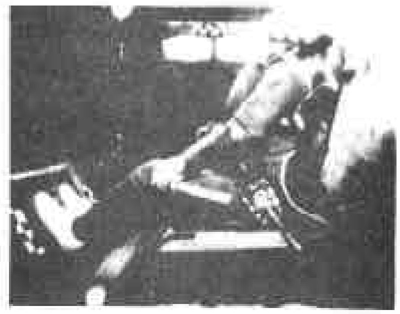
Figure 15. Occupant Response, Run No. 978

16a. t = 0 msec

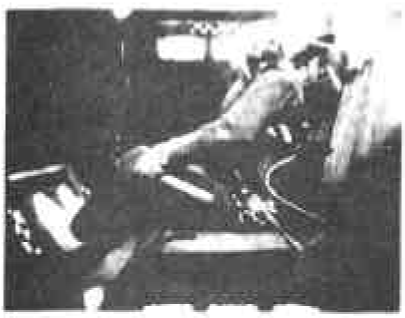


16b. t = 8 msec

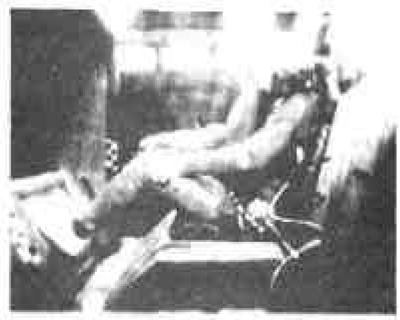
16c. t = 17 msec



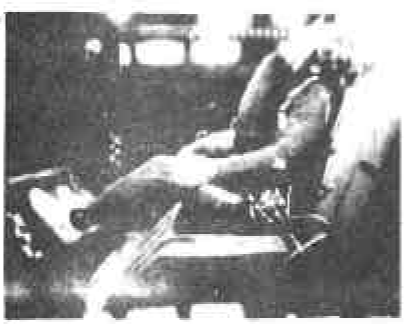
16d. t = 54 msec



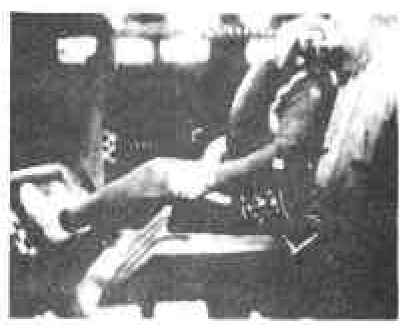
16e. t = 85 msec



16f. t = 146 msec



16g. t = 180 msec



16h. t = 213 msec

Figure 16. Occupant Response, Run No. 979

around the right arm with the Doppler transducers contacting the skin directly over the brachial artery through slits in the protective clothing. A quick release connector for cuff inflation and transducer excitation was taped to the seat during the run. Approximately one minute elapsed before blood pressure readings could be taken after the run. No blood pressure information was lost due to cuff slippage or equipment malfunction.

Respiration - Severe impact to the chest (thoracic cavity) cannot only cause damage to the heart but also precipitate possible respiratory problems. Thus, it is important to note respiratory rate and uncalibrated volume. Due to the nature of the tests, it was not feasible to monitor respiration in any of the classical modes where thermistors, flowmeters, or pneumotaclographs would be located in the vicinity of the mouth. The configuration of the restraining harness precluded the use of an impedance pneumograph.

A novel and reliable method was previously devised and an instrument developed based on the principle of changing electrical conductivity of the heart caused by displacement of the heart by the inflation and deflation of the lungs. This phenomenon manifests itself as a variation in R wave amplitude. To retrieve respiration from the ECG, the R wave amplitude peak is detected and the result is integrated.

Figure 17 illustrates an ECG and respiration trace on a compressed time scale. The variation of the R wave peaks can be seen more clearly with the slower chart speed.

I. Program Protocol

Because of the concern for subject welfare, a rigorous program protocol was established in compliance with Standard Operating Procedures 9.1.4 of the Institute. The S.O.P. requires that any program, in which human volunteers are to be subjected to extreme stress or hazards that might endanger their health, welfare or state of being, must first be approved by the Committee for the Protection of Human Subjects. Committee members are competent to review the proposed activities and exercise independent judgement that the subjects' rights and welfare are adequately protected--that the risks to the subjects are outweighed by the potential benefits to be gained--and that the procedures for obtaining informed consent are adequate and appropriate. The program plan as presented to the Committee addressed the following items:

1. Restraint system description
2. Specific test procedures and protocols
3. Volunteer's Informal Consent Form
4. Description of instrumentation and data interpretation to evaluate impact severity

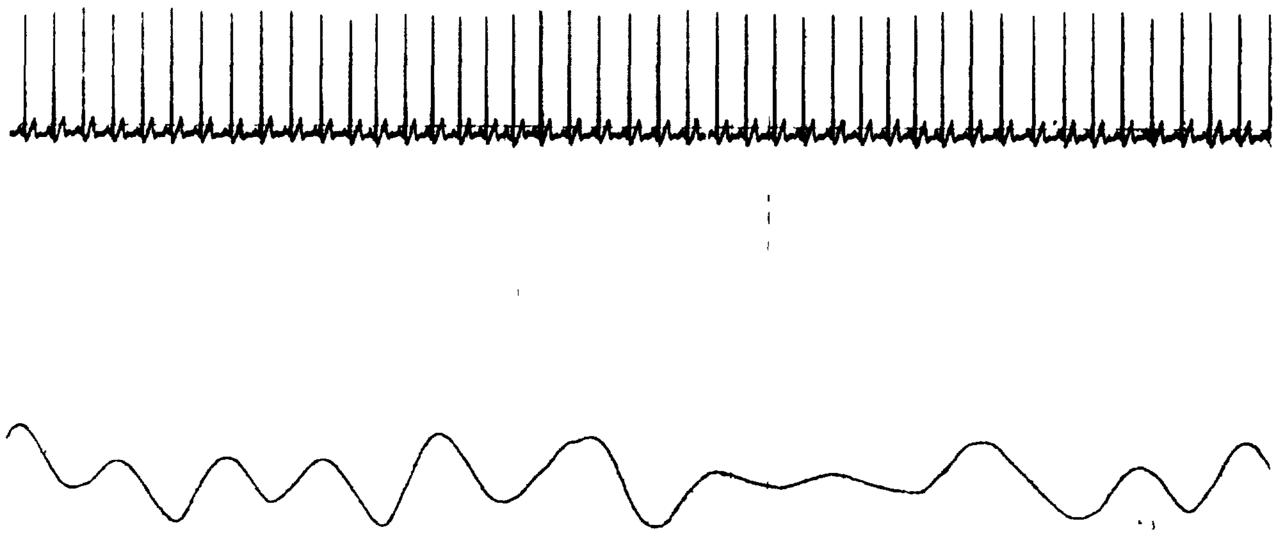


FIGURE 17 - ECG AND RESPIRATION PATTERN

(Top and Bottom Trace, Respectively)

5. Emergency facilities and contingency procedures.

In granting approval to conduct human testing, the Committee and project management agreed that a program review would be made following the completion of the 17.5 mph (28.2 kph) level. The review was conducted, and the Committee granted approval to continue the program to completion unless conditions occurred that would require their attention.

Internal to the project, staff meetings were routinely scheduled within 24 hours after a test to review film and data from the previous tests. As each severity level was initiated, the decision to conduct the human segment was made only after the review data derived from the two dummy tests at that level indicated acceptable severity levels. Following each human test, both medical and engineering personnel carefully assessed the film records, the reduced data (HSI, CSI, HIC, head and chest 3ms max. resultant accelerations, sled parameters, EKG traces, respiration, blood pressure, and belt loads), hazards as created by operational problems (if any were observed), and the taped post test interview documenting post test trauma. As the volunteers were evaluated in light of these factors, the testing schedule was formulated around those volunteers who in the opinion of staff medical and engineering personnel would most likely experience a good ride.

J. Volunteer Protocol

The volunteers utilized in the program were selected from an existing panel on the basis of anticipated impact response and anthropometrics. Twelve (12) volunteers were recruited ranging in age from 20 to 28, each having some experience with sled impact tests. Table 4 provides details in regards to anthropometric measurements and age.

All volunteers had been required in preparation for a prior program to pass a physical examination which included examination of heart, lungs, ENT, eyes, hearing, reflexes, muscle and joint motion and strength, pulse rate, B/P, certain anthropometric measurements, ECG after exercise, and a psychologic evaluation. All subjects also had had X-ray evaluation of the entire spine and all major bones and joints by a series of 22 X-ray views. Any significant abnormality such as arthritis, calcified cartilaginous fragments, ununited fracture, cortical thinning, etc. was a cause for rejection. In addition, each volunteer had enzyme studies performed in the pretest period to include SGOT, CPK, and LDH. This provided baseline data for needed later comparison with enzyme values obtained in the post impact period should a question of possible myocardial contusion arise. Prior to this series of tests, an interval type of history and physical examination was performed in order to insure ourselves of the fact that no significant deterioration of health had occurred since the last program in which these volunteers had participated.

Table 4

Physical Measurements of Volunteers

Subject	Age	Weight	Stature	Sitting Height	Acromion-Radiale	Forearm-Grip	Buttock-Knee	Sitting Knee Height
1	24	201	183.5	93.5	34.7	39	63	57
13	21	146	178.6	90.6	38.8	37.8	60.3	56.8
16	24	146	180.3	90.7	37.3	38	56.5	54.3
21	25	190	179	91.3	37.5	39.5	59.6	56.4
24	24	176	181.5	93.5	38.5	37.5	59.4	56.5
28	28	164.5	177	93.5	35	38	57.5	53.8
33	27	210	180	94.5	37.5	38	61.5	58
35	23	166	178	92.5	40	39.5	59	55.4
36	21	160	184	89.5	40	40.5	65.5	57.3
40	22	185	176.5	91	37	38	57.5	54
41	22	173	176	90.5	38	37.5	58	53.5
42	20	171	178.4	91.3	37.8	38.2	61.2	56.2
50th percentile dummy		164	176	90.7				
95th percentile dummy		217	185.7	96.5				

Weight in pounds. All measurements in cm.

Upon satisfactory completion of the medical examination, the subjects were given a verbal orientation which included an opportunity to view a representative dummy sled test, an explanation of the test systems, program objectives, and an explanation of potential hazards (See Appendix B). Only after completing the entire orientation, was the volunteer asked to sign an Informed Consent Form, Appendix B.

Each volunteer expressing his desire to participate in the program was "fitted" to the test fixture. The fitting procedure consisted of seating the volunteer in the buck and adjusting the seat fore and aft until a position both comfortable and functional was determined. In this seating position, the distance from the left lap anchor point to the H-point was measured and recorded. This information was required in order to make up restraint system assemblies in advance since the position of the inflator was not adjustable once installed in the buck.

As each volunteer reported for his production test, he received a pre-test briefing. If available, he was allowed to view test film of the preceding human run and his last run. Each film viewed was critiqued to point out good and bad characteristics. There is no doubt that the pre-test briefings assisted the volunteers and helped them learn how to ride and prepare mentally for the impact.

For each human test (indoctrination and production) the physician in attendance administered a brief physical examination of the volunteer to check the heart, lungs, joint mobility, coordination, and equilibrium. The subject was then instrumented for ECG and blood pressure. Each volunteer wore tight fitting "ski pajama" tops and bottoms and low top tennis shoes. For additional protection, each volunteer was required to use ear plugs (to preclude potential hearing loss that might be caused by the report of the inflator), a rubber mouthpiece for tooth protection, plastic goggles over the eyes, a wet suit hood over the head (to prevent abrasions of the neck as caused by occupant motion relative to the shoulder band), chamois on the right arm, chest, and abdomen (to prevent penetration of the skin by metal fragments), and foam pad over the right inguinal region to attenuate the "slapping" effect of the lap band.

In all tests, the volunteers were seated in the forward facing position, and centered laterally along the seat line. To consistently tighten the shoulder and lap bands of the restraint system, the same team members performed the function each time. The shoulder band was tightened so that two fingers would snugly fit between the band and volunteer in the area of the right clavicle. The lap band was similarly tightened with two fingers fitting snugly between the band and hip of the volunteer.

Pre-test briefing emphasized the importance of coordinated body bracing. Each volunteer was instructed on hand position, head position, and muscle tone. His hands were placed on his thighs (just above the knee) with his thumbs inward. His head was upright in a normal driving position.

Following the test, a quick look at the vital signs was made to determine volunteer condition. An interview and examination were made to obtain subjective reaction as well as evaluate and record trauma. Subsequent to this post-impact examination, each subject completed a survey of physical symptoms experienced, and indicated the location of symptoms appropriately on the Physical Symptoms Survey Sheet (Figure 18). Subjective reports were also completed by the subject immediately post test, and after 24 and 72 hours (Figure 19).

K. Data Reduction

To provide the time variant and accumulative quantities indicative of crash severity and/or injury (HSI, HIC, etc), eleven (11) data channels were digitized (sled acceleration, time zero, chest triaxial accelerations, head triaxial accelerations, head biaxial accelerations, head axial acceleration) at a sampling rate of 2000 Hz per channel. Each data channel was filtered prior to digitization in accordance with the specifications of SAE J211a.

Within five minutes post impact, the computer had processed the digitized data, and output was available. Figure 20 is a representative sample of the immediate output. The mathematical expressions used to compute HSI, CSI, HIC, sled velocity, head resultant acceleration, chest resultant acceleration, head angular acceleration, and head angular velocity are presented in Appendix C. Beyond the data reduction as obtained immediately after the test, additional reduction was done to correct toe pan force values for inertial loading of the foot load plate.

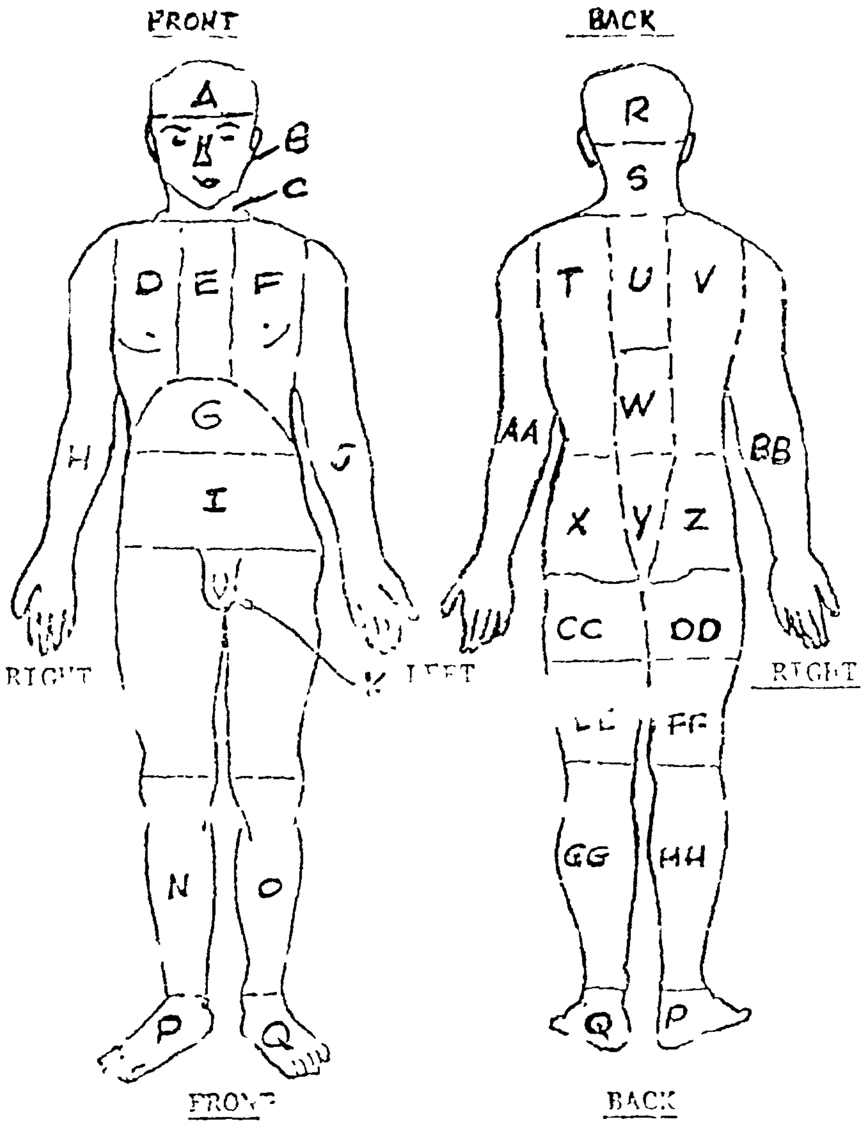
The system of transducers used to measure toe pan loads was constructed in such a manner that the indicated loads were composed of two forces, each having components in the directions of measurement. One set of forces (set meaning the left and right) was due to the forces generated by the occupant while the other set was due to the inertial forces of the load plate during impact. The peak resultant toe pan loads tabulated in Table 5 were corrected by subtracting from the total indicated loads the appropriate value of inertial loading as discussed in Appendix C.

To determine the equivalent stopping distance for a simulated impact on the SwRI system, the velocity vs. time curve was integrated. The derived value, as for a real barrier crash, is composed of two equivalent parts; one part is non recoverable in the form of permanent crush while the other part is recoverable in the form of elastic deformation. For the 32.5 mph (52.3 kph) series the total dynamic crush would be the area

INFLATABAND PROGRAM

Figure 18

PHYSICAL SYMPTOM SURVEY



LETTERING CODE:

A.____	N.____	b ____
b.____	O.____	CC.____
C.____	P.____	DD.____
D.____	Q.____	EE.____
E____	R.____	FF.____
F.____	S.____	GG.____
G.____	T.____	HH.____
H.____	U.____	
I.____	V.____	
J.____	W.____	
K.____	X.____	
L.____	Y.____	
M.____	Z.____	

SEVERITY CODE:

1. No Symptoms
2. Mild Pressure
3. Moderate
4. Slight Discomfort
5. Definite Discomfort
6. Mild Pain
7. Moderate Pain
8. Severe Pain

I. The drawings above show the human Body divided into segments or areas with each segment marked with a letter, or letters, of the alphabet. A listing of the letters, lettering code, with a blank space after each one is to the right of the human body drawings. Numerical designations make up the severity cod [illegible] the lettering code.

II. Using the lettering code and the severity code, indicate the location and severity of any physical symptoms you experienced as a result of the test you just made. For example: A severe middle back pain would be designated as "W8". You would enter the [illegible] "8" on the [illegible] after the letter "W" in the lettering code list [illegible].

III. Please try to locate and classify in this way all the symptoms which you felt. However, if you experienced symptoms which you feel cannot be expressed in this manner [illegible] in the [illegible] section (IV below), using the back of this sheet if more [illegible] is needed [illegible] medical personnel as soon as possible.

IV [illegible]

NAME ____________________ RUN# ________ DATE ____________

SLED SUBJECTIVE REPORT

Debriefing Sheet

Name: ______________________________ Date: ______________________________

Run No. ______________________________

Check the appropriate columns below for each item in each time per

Immediately Post-Run YES	Immediately Post-Run NO		24-hrs. Post-Run YES	24-hrs. Post-Run NO		72-hrs Post-Run YES	72-hrs Post-Run NO	
								Headache(s)
								Disorientation, confusion
								Blurred or double vision
								Faintness or dizziness
								Pain on inspiration or expiration
								Pain (describe fully below as well as presumed reason)
								Eye trouble
								Ear, nose or throat trouble
								Palpitations
								Blood in sputum, urine, stool or vomitus
								Black "tarry" stool
								Weakness
								Pain on swallowing
								Stomach or intestinal [illegible]

Immediate post-run remarks:

Apprehension:

Strapping:

Body Position

Acceleration.

Impact

General post-run feeling.

Overall opinion of ride:

(Use back of this sheet to elaborate on any affirmative replies to items on Debriefing Sheets.)

Figure 19.

RUN NO. 973
5/14/75 50% DUMMY 11-4020-101

CAL
.000 -8.062 8.906 8.757 9.160 8.238 8.184 8.905
7.789 8.808 9.365

OFFSET
.000 .195 .139 .178 .136 -.271 .020 -.078
.018 -.030 .203

TIME	AC-SL	VL-SL	AC-HD	AC-CH	SI-HD	SI-CH	AA-HD	AV-HD
.000	-.4	-.0	.7	1.3	0	0	358	.4
.025	10.8	3.6	23.6	14.3	51	14	3285	18.1
.050	17.7	12.5	12.5	18.3	64	39	474	29.9
.075	15.2	22.0	22.8	18.2	114	73	1429	59.7
.100	9.4	29.6	18.4	16.6	169	109	1643	71.3
.125	3.0	32.7	14.4	8.5	200	125	1208	56.7
.150	-.3	32.6	8.8	1.7	213	127	1019	46.8
.175	-.0	32.4	7.1	3.8	217	128	1271	45.8
.200	-.5	32.2	35.4	2.7	245	129	2781	74.6
.225	-.4	32.1	4.6	3.7	285	130	13168	165.9
.250	-.7	31.8	4.7	2.1	286	130	1299	44.9

MAX SLED ACCEL. IS 19.9 AT .037 SEC

MAX SLED VEL. IS 32.9 AT .129 SEC

HEAD-3MS MAX OF 36.2 AT .202 SEC
CHEST-3MS MAX OF 19.9 AT .024 SEC

HEAD-3MS MAX OF 31.7 AT .022 SEC
CHEST-3MS MAX OF 19.2 AT .088 SEC

HEAD-3MS MAX OF 31.7 AT .200 SEC
CHEST-3MS MAX OF 18.7 AT .060 SEC

HEAD-3MS MAX OF 24.6 AT .089 SEC
CHEST-3MS MAX OF 17.8 AT .030 SEC

HEAD-3MS MAX OF 24.3 AT .073 SEC
CHEST-3MS MAX OF 16.6 AT .101 SEC

HIC IS 197.1 DURING .011 TO .205 SEC

CAL
.000 -8.062 8.919 8.752 9.151 8.260 8.200 8.910
7.781 8.800 9.354

OFFSET
.000 .193 .143 .168 .127 -.266 .027 -.084
.003 -.040 .188
END OF FILE
STOP
:

Figure 20. Computer Print-out

"A_T" with "Ae" being analogous to the elastic deformation, Figure 21. The permanent deformation may be determined by subtracting Ae from AT. Typical values for the final test series were as follows:

indicated dynamic crush ≈ 29.6 in (75.1 cm)
indicated elastic deformation ≈ 1.C in (2.5 cm).

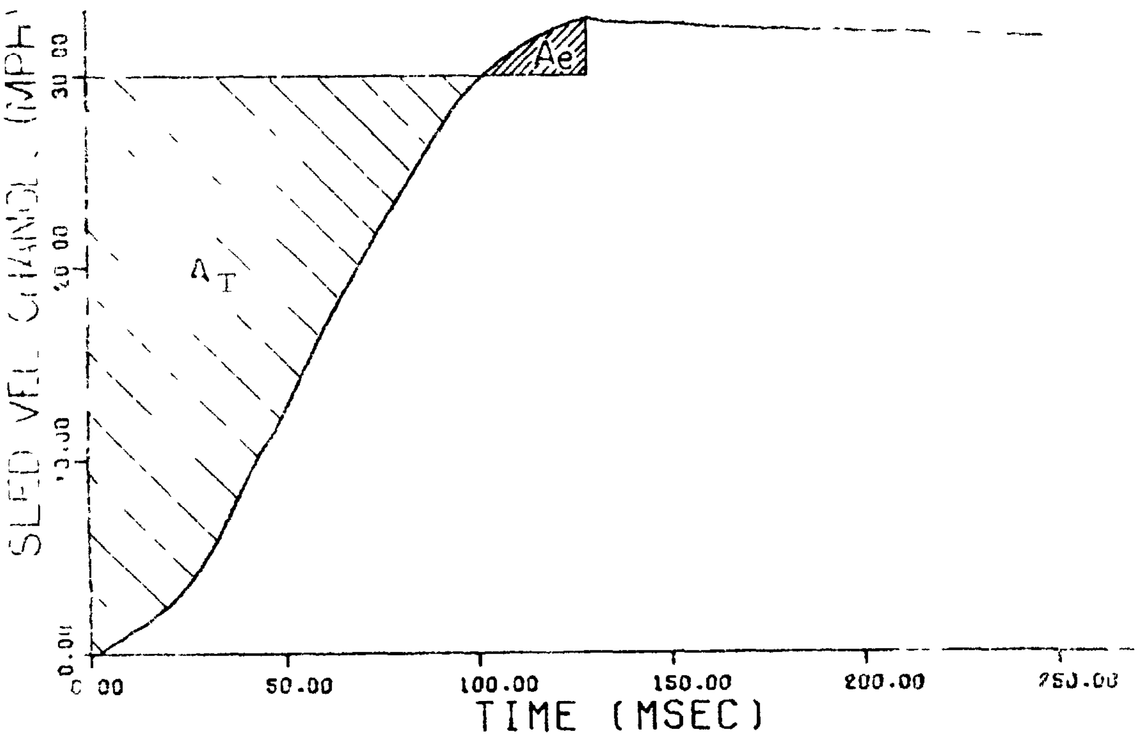


Figure 21. Velocity vs. Time, Test 973

Table 5

Human Volunteer Data Summary

Run No.	Vol. No.	Sled Acc. g's	Sled Δv mph/kph	HSI	CSI	HIC Interval ms	Head 3 ms Max. Acc. g's at t_2	Chest 3 ms Max. Acc. g's at t_2	Left Lap Belt Load, lbf	Right Lap Belt Load, lbf	Shoulder Belt Load, lbf	Toe Pan Load, lbf Left/Right
884	16	6.8	12.3/19.8	45	33	32.4 19-210	18.0 at 37	20.0 at 25	575	350	250	320/302
886	36	6.8	12.3/19.8	61	16	42.5 18-50	23.1 at 23	13.2 at 25	400	300	350	394/372
887	33	6.8	12.2/19.6	71	19	39.8 13-159	31.9 at 149	11.4 at 37	600	200	400	371/498
898	1	8.2	14.9/24.0	52	27	42.1 20-107	17.3 at 41	14.6 at 29	425	225	375	620/492
900	42	8.3	15.0/24.2	63	37	44.6 19-88	26.4 at 27	15.6 at 24	550	250	450	533/419
901	41	8.2	14.9/24.0	45	24	37.6 21-109	15.5 at 76	12.0 at 29	500	200	325	550/417
909	13	10.2	17.7/28.5	92	44	70.8 18-128	19.7 at 89	16.8 at 29	500	200	200	732/506
913	21	10.0	17.6/28.3	87	45	68.5 31-118	18.6 at 85	15.6 at 34	640	280	300	671/544
914	40	10.0	17.5/28.2	81	39	62.2 19-117	18.4 at [illegible]9	15.6 at 34	700	325	Sig. Loss	468/376
922	28	11.2	20.5/33.0	81	42	[illegible]8.9 17-119	18.6 at 32	14.5 at 33	800	210	450	552/465
924	24	11.1	20.5/33.0	[illegible]	42	[illegible]0.1 24-117	17.2 at 84	15.1 at 62	675	200	450	939/570
925	35	11.6	20.8/33.5	7[illegible]	41	61.4 [illegible]	19.3 at 30	15.8 at 32	600	250	450	642/571
932	13	13.0	22.4/3[illegible].1	[illegible]	[illegible]	103.[illegible] [illegible]	22.2 at 87	17.6 at 30	800	250	350	[illegible]96/532
934	1	13.5	Accel. Break-up	[illegible]	53	[illegible]	22.4 at 31	17.0 at 63	750	300	700	541/566

g level for 3ms inter al [illegible] the inter al

IV. PROGRAM RESULTS

Program results are presented in the form of tabulated data sheets (Table 5), reference point trajectories (Figures 22 through 36), and curves indicative of occupant response as a function of impact (Figures 37 and 38). These items summarize information derived from photographic coverage of the 32.5 mph (52.3 kph) series and the analog transducer signals, Appendix D. The photographically derived information (Figures 22 through 36) was not corrected for camera parallax and should be used only as a relative indicator for comparison of responses. Medical observations are documented in Tables 6 and 7.

Table 5

Human Volunteer Data Summary (cont'd)

Run No.	Vol. No.	Sled Acc. g's	Sled Δv mph/kph	HSI	CSI	HIC Interval ms	Head 3ms Max. Acc. g's at t_2	Chest 3 ms Max. Acc. g's at t_2	Left Lap Belt Load, lbf	Right Lap Belt Load, lbf	Shoulder Belt Load, lbf	Toe Pan Load lbf Left/Right
937	21	12.7	22.1 / 35.6	128	40	102.2 34-115	23.2 at 92	15.3 at 32	900	350	535	605 / 778
943	41	14.7	24.4 / 39.3	164	79	113.9 18-187	26.7 at 79	18.8 at 80	1050	500	635	551 / 534
945	40	14.7	24.3 / 39.1	248	95	189.5 16-203	26.4 at 182	20.5 at 60	1325	400	500	597 / 387
946	16	14.7	25.1 / 40.4	148	85	115.6 17-123	21.5 at 34	20.3 at 34	1025	250	350	546 / 505
955	24	15.7	27.1 / 43.6	123	79	97.3 16-121	21.7 at 83	19.0 at 60	1000	300	850	461 / 958
957	35	16.1	28.2 / 45.4	154	53	126 16-118	23.2 at 31	15.2 at 32	800	300	600	S. L. / 585
958	28	16.0	27.6 / 44.4	232	107	169.9 23-207	27.1 at 198	19.2 at 77	1560	400	710	563 / 543
966	16	18.3	30.2 / 48.6	253	126	173.2 63-125	31.8 at 92	21.6 at 57	1200	350	400	452 / 579
968	40	17.6	29.3 / 47.2	291	100	208.4 18-205	33.6 at 188	20.6 at 65	1250	475	1000	862 / 491
969	1	17.8	29.3 / 47.2	216	66	174.4 16-122	27 at 23	17.8 at 72	1075	325	850	894 / 760
976	13	19.6	32.3 / 52.0	371	120	244.0 25-203	40.4 at 194	20.5 at 107	1600	350	500	712 / 888
978	24	19.7	32.3 / 52.0	308	137	220.2 15-200	28.9 at 86	21.3 at 66	1700	425	800	1123 / 611
979	28	19.6	32.1 / 51.7	361	164	238.7 27-199	42.0 at 181	22.9 at 89	1540	480	740	686 / 507

* g level for 3ms interval where t_2 is the time at the end of the interval

Table 5

Dummy Data Summary

Run No.	Dummy %	Sled Acc. g's	Sled Δv mph/kph	HSI	CSI	HIC Interval ms	Head 3ms Max. Acc. g's at t_2**	Chest 3ms Max. Acc. g's at t_2**	Left Lap Belt Load, lbf	Right Lap Belt Load, lbf	Shoulder Belt Load, lbf	Toe Pan Load lbf Left/Right
881	50	7.2	13.5 / 21.7	83	32	49.8 14-87	33.9 at 26	20.0 at 18	800	Sig. Loss	450	344 / 424
882	95	6.9	13.2 / 21.3	66	33	50.9 16-93	18.2 at 31	15.5 at 29	750	425	600	392 / 541
895	50	8.4	13.5 / 24.5	76	44	48.2 12-97	27.2 at 23	20.7 at 17	560	175	220	427 / 667
897	95	8.2	14.8 / 23.8	115	53	84.7 13-90	25.2 at 29	19.3 at 28	750	230	550	428 / 473
906	50	10.3	17.9 / 28.8	126	43	80.0 11-99	37.1 at 21	22.6 at 17	750	275	210	430 / 570
908	95	9.9	17.4 / 28.0	133	48	96.3 17-110	21.7 at 45	15.6 at 35	890	350	700	508 / 499
918	50	11.2	20.5 / 33.0	138	83	101.9 11-150	25.6 at 24	24.1 at 16	825	300	360	447 / 599
920	95	11.1	20.2 / 32.5	161	Sig. Loss	108.0 13-112	29.2 at 24	Sig. Loss	1200	500	725	427 / 526
929	50	12.1*	20.0* / 32.2	121*	77*	84.5* 12-205	27.6* at 28	29.8* at 16	1050	350	600	S.L. / 605
931	95	12.7	22.1 / 35.6	202	59	134.8 11-110	33.4 at 23	19.6 at 25	1450	525	850	490 / 507

* Signal Break-up Experienced

** g l vel for 3ms interval where t_2 is the time at the end of the interval

.able 5

'ummy Data Summary (cont'd)

	Dummy %	Sled Acc. g's	Sled Δv mph/kph	HSI	CSI	HIC Interval ms	Head 3ms Max. Acc. g's at t_2	Chest 3ms Max. Acc. g's at t_2	Left Lap Belt Load, lbf	Right Lap Belt Load, lbf	Shoulder Belt Load, lbf	Toe Pan Load lbf Left/Right
	50	15.1	25.2/40.6	214	107*	143 10-205	36.4 at 197	34.4‡ at 16	1250	Sig. Loss	500	S.L./676
	95	14.9	24.3/39.1	220	125*	171.8 11-124	27.2 at 28	22.2‡ at 27	1550	700	1100	523/578
	50	15.7	27.5/44.3	266	101	178.6 11-119	42.3 at 23	25.4 at 16	1150	450	550	472/606
	95	15.9	27.1/43.6	236	65	171.9 13-121	32.9 at 24	15.6 at 41	1725		1150	510/614
	50	18.2	30.8/49.6	424⊙	111	264.5⊙ 11-200	55.4⊙ at 192	21.8 at 15	1760	490	800	489/631
	95	17.7	29.7/47.8	256	114	181.5 15-123	28.9 at 81	21.7 at 99	1950	850	1200	474/686
	50	19.9	32.9/53.0	286	130	202.3 11-210	36.2 at 202	19.9 at 24	1935	600	1250	439/693
	95	19.3	32.0/51.5	326	Sig. Loss	243.7 12-121	30.7 at 79	Sig. Loss	2000	950	1450	565/856

ignal Loss on Chest Z Axis

ummy May Have Had Broken Neck

level for 3ms interval where t_2 is the time at the end of the interval

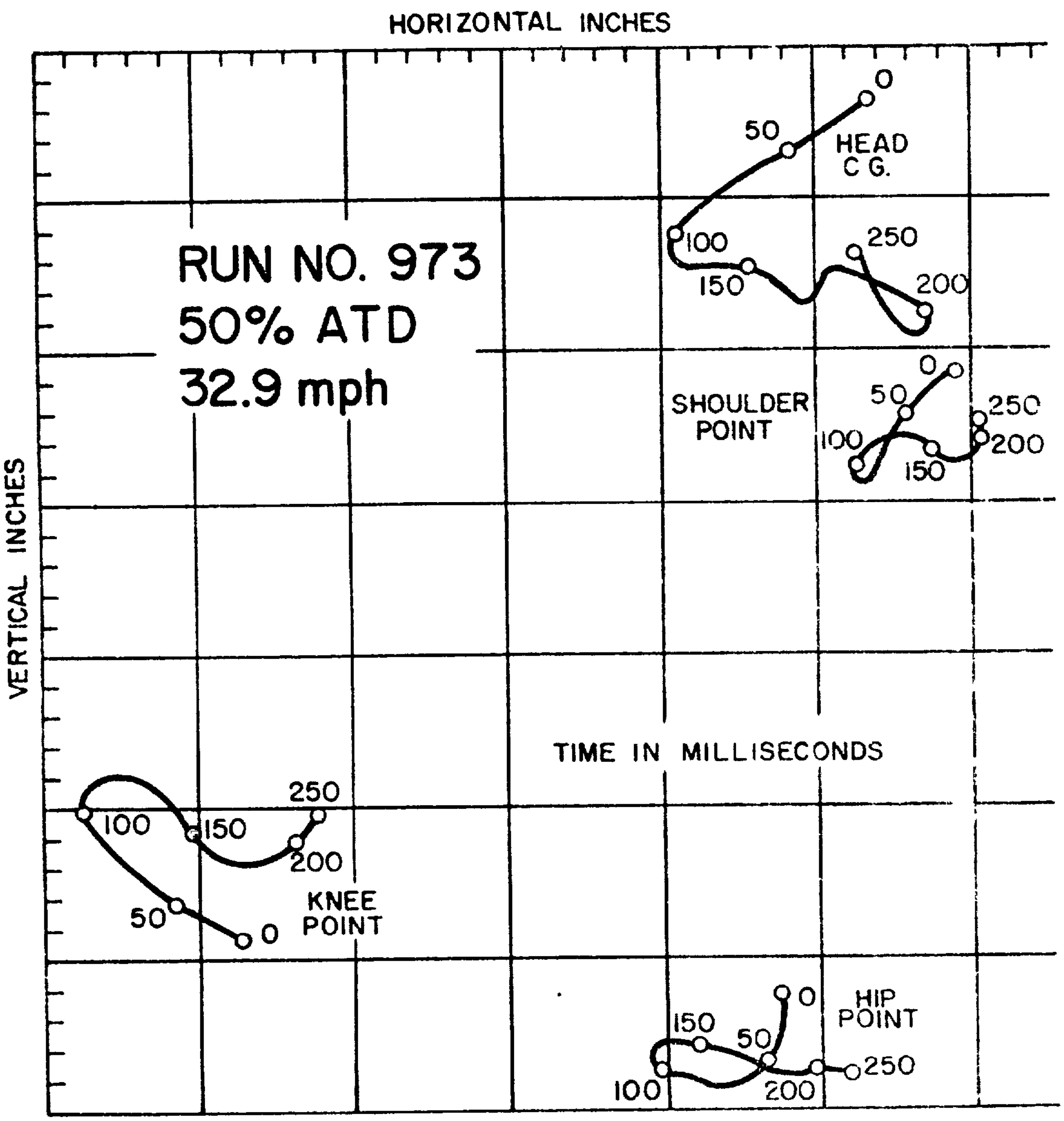


Figure 22. Reference Point Trajectories

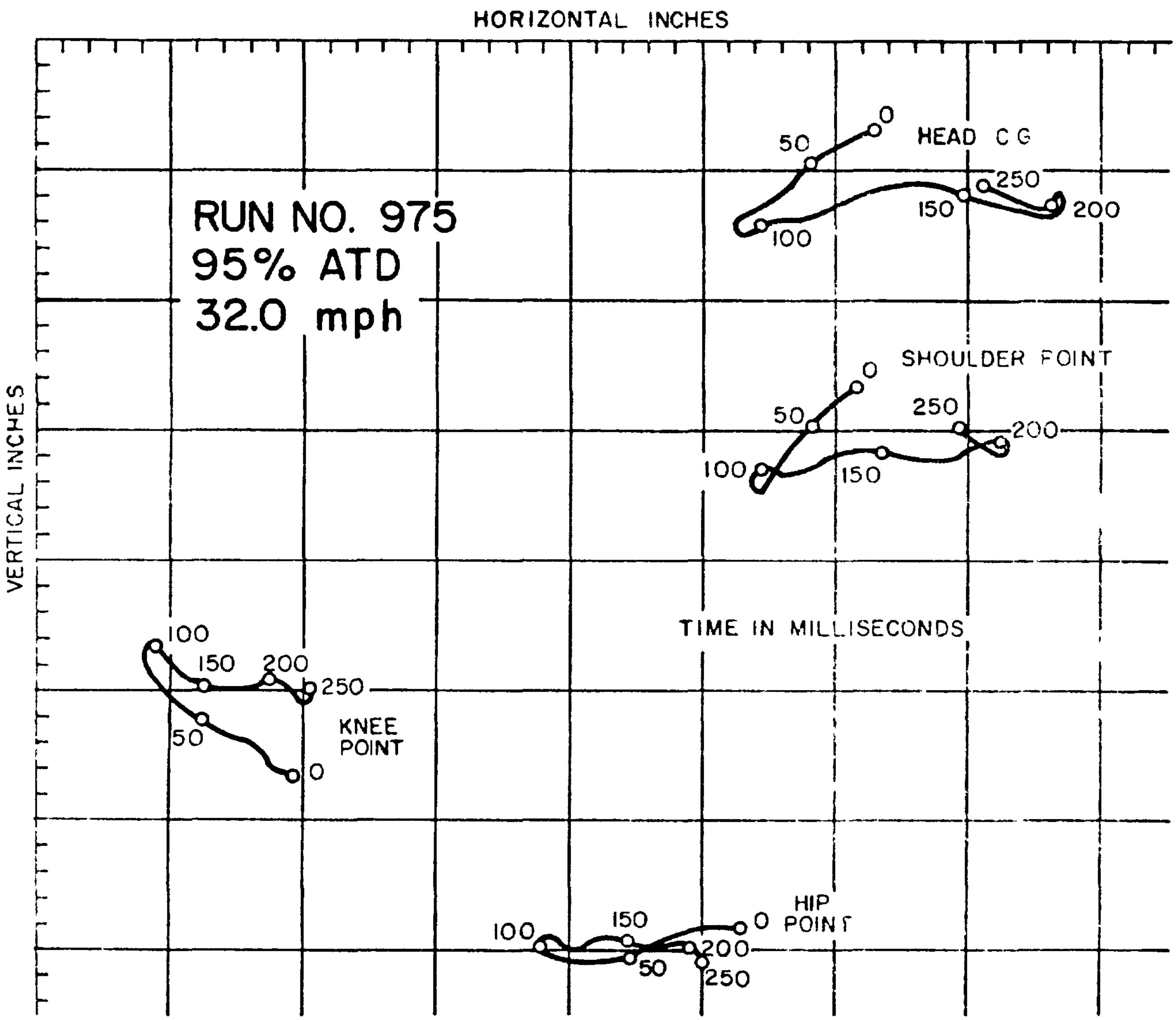


Figure 23. Reference Point Trajectories

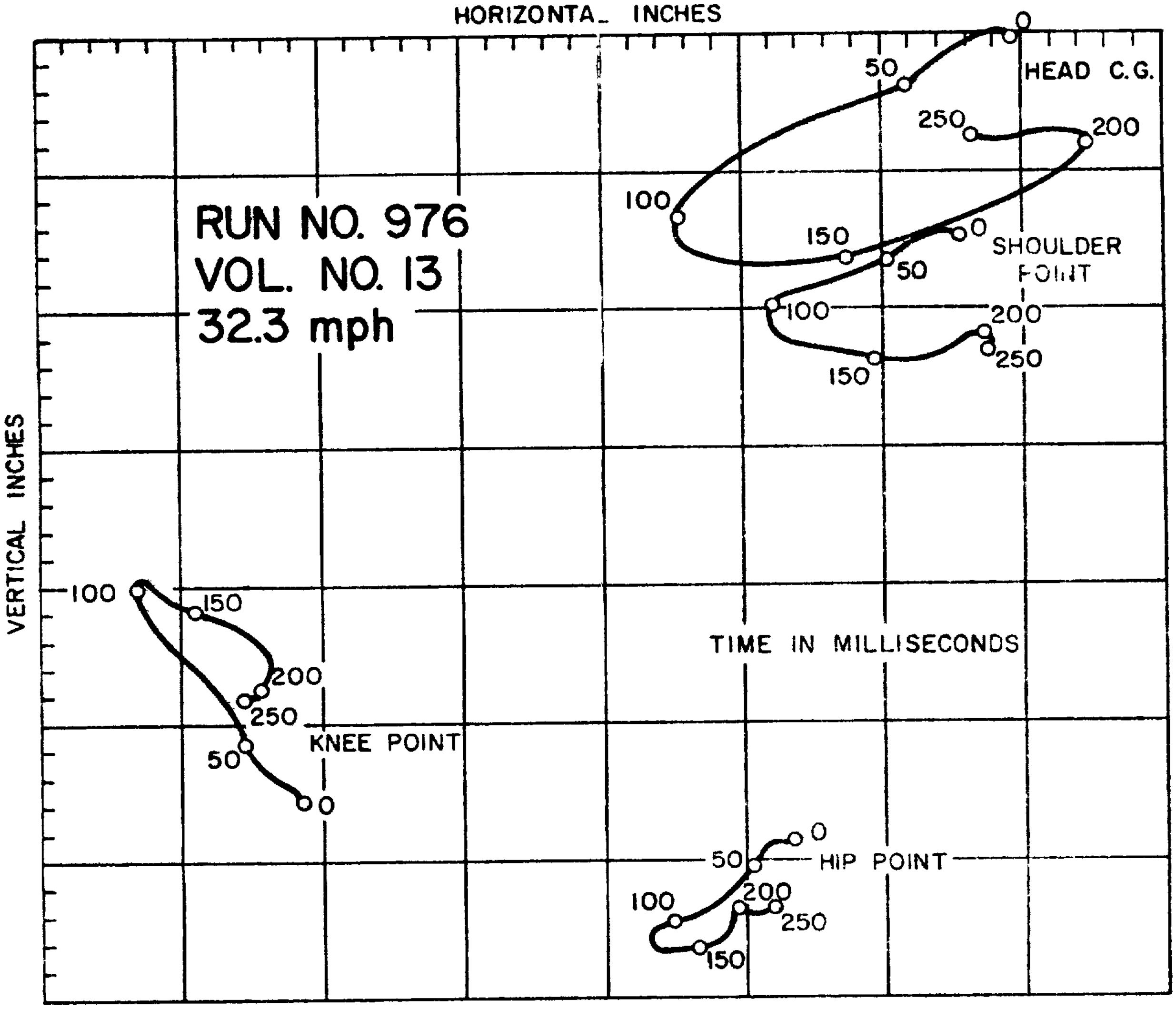


Figure 24. Reference Point Trajectories

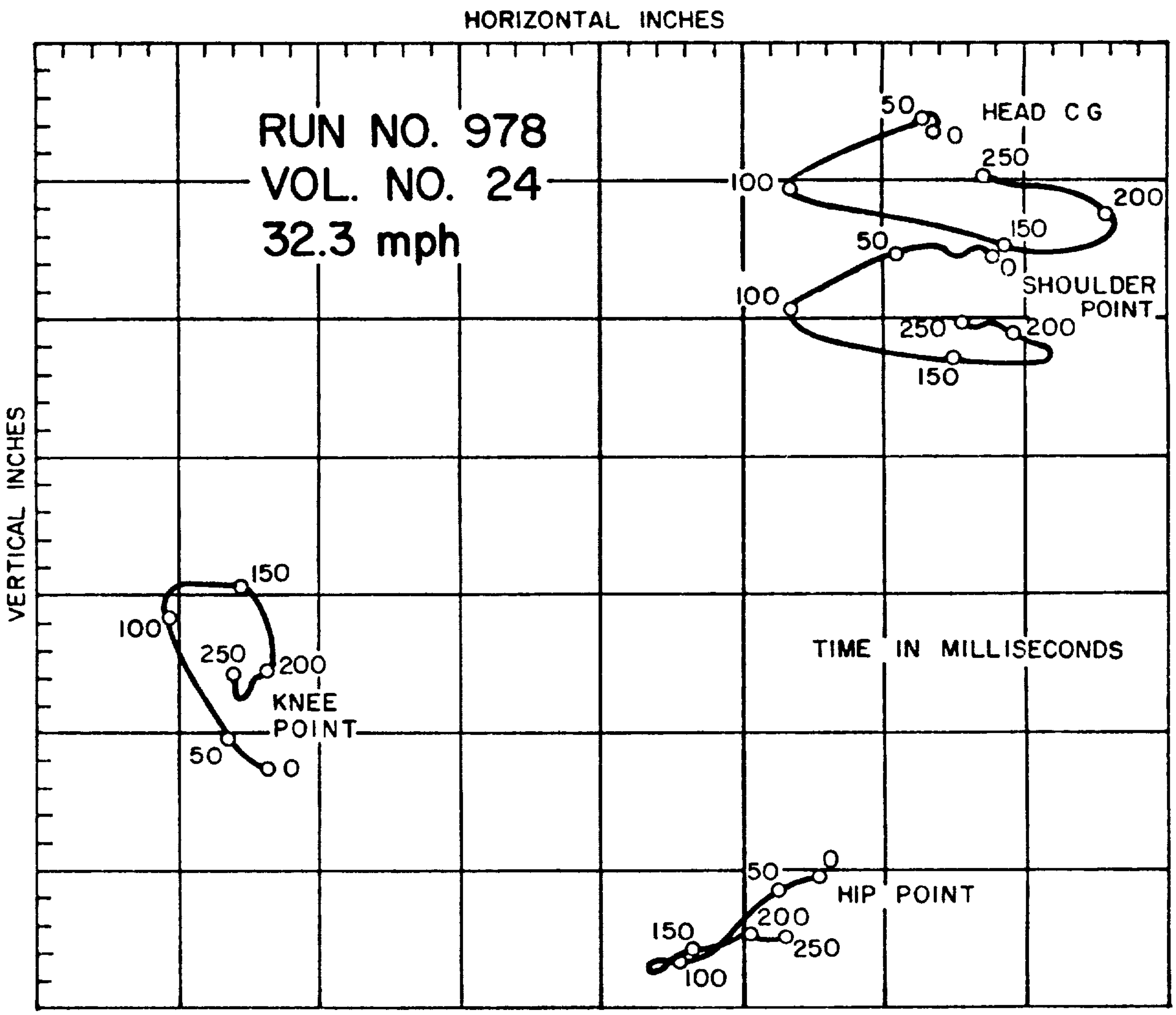


Figure 25. Reference Point Trajectories

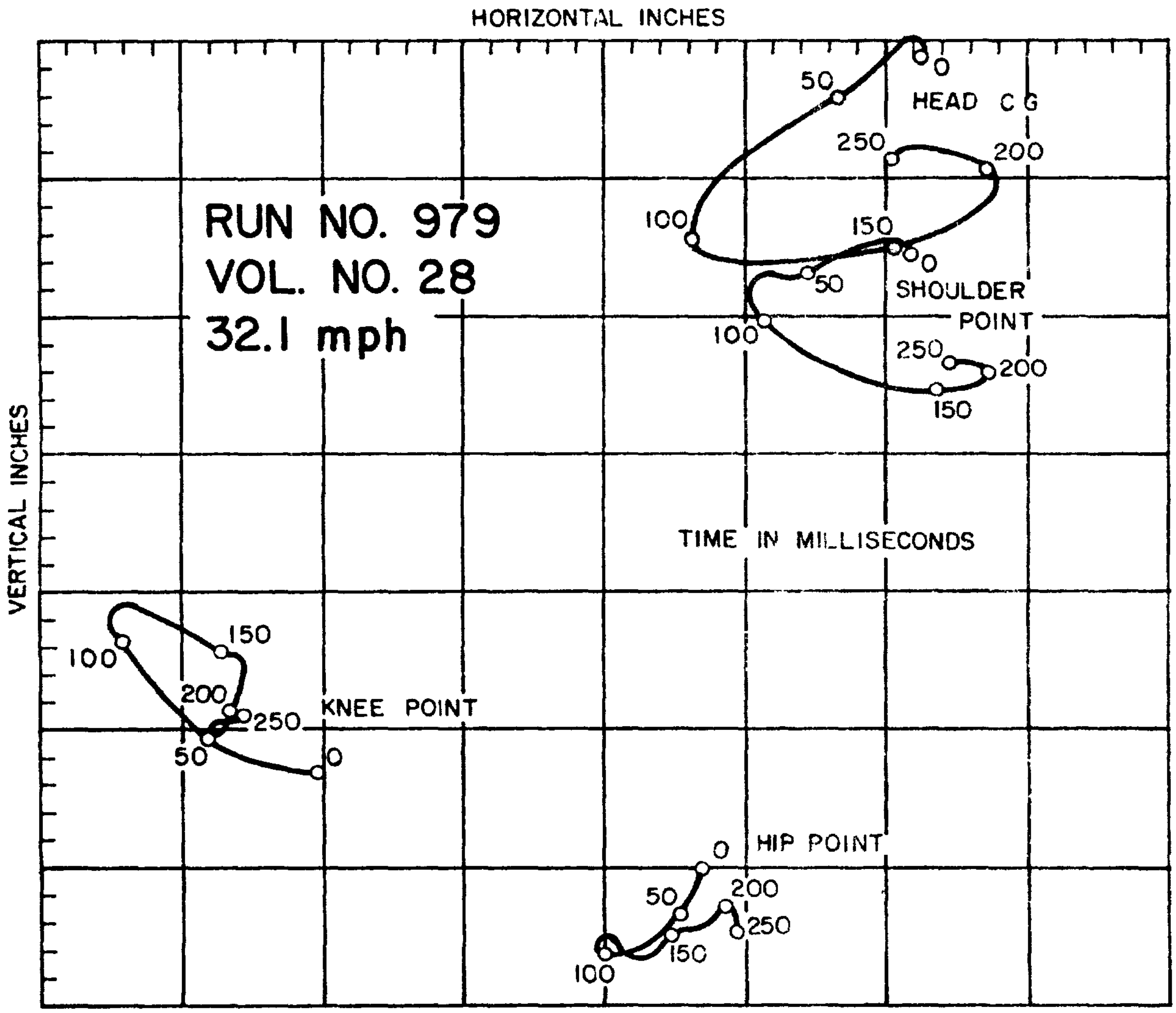


Figure 26. Reference Point Trajectories

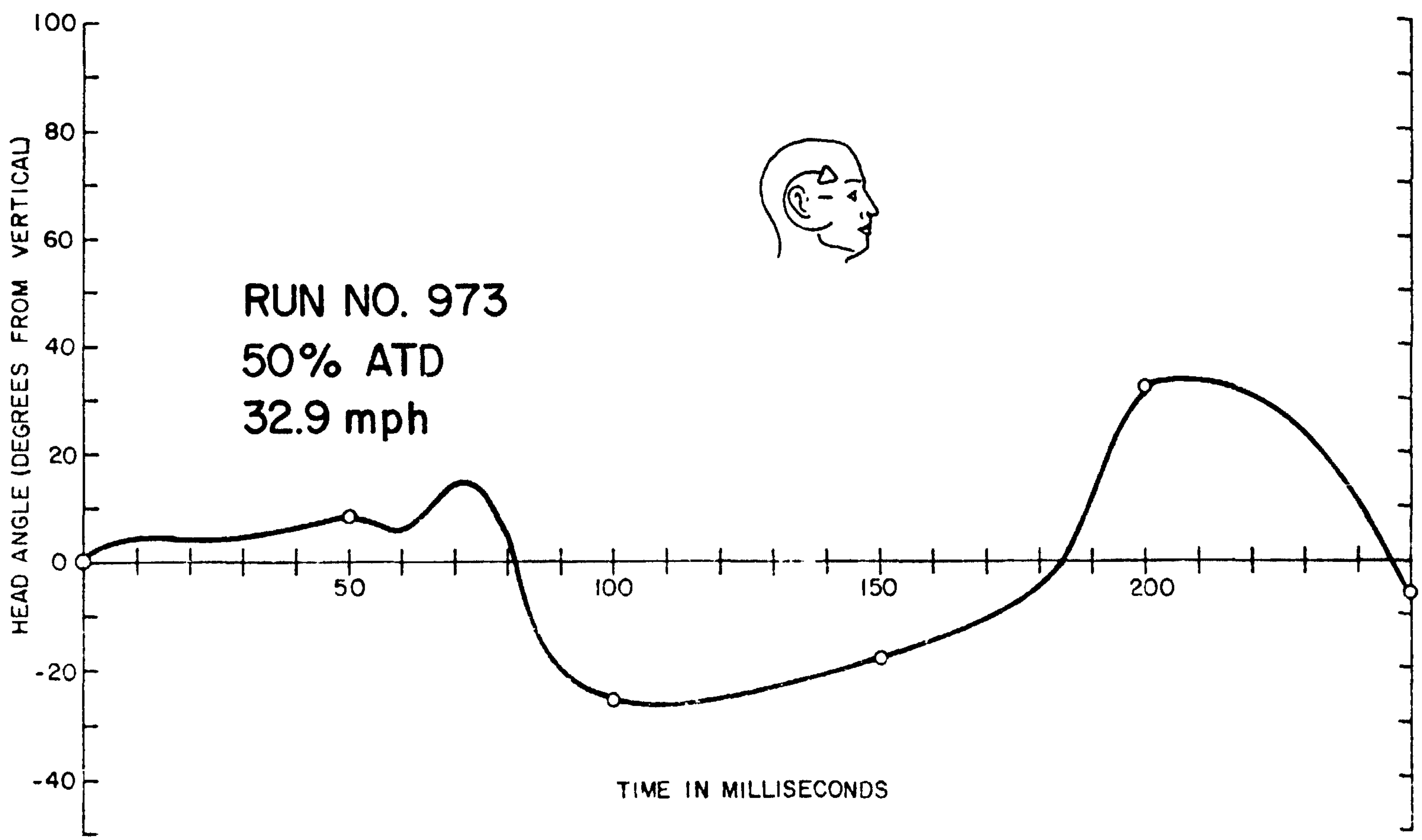


Figure 27. Head Rotation Response

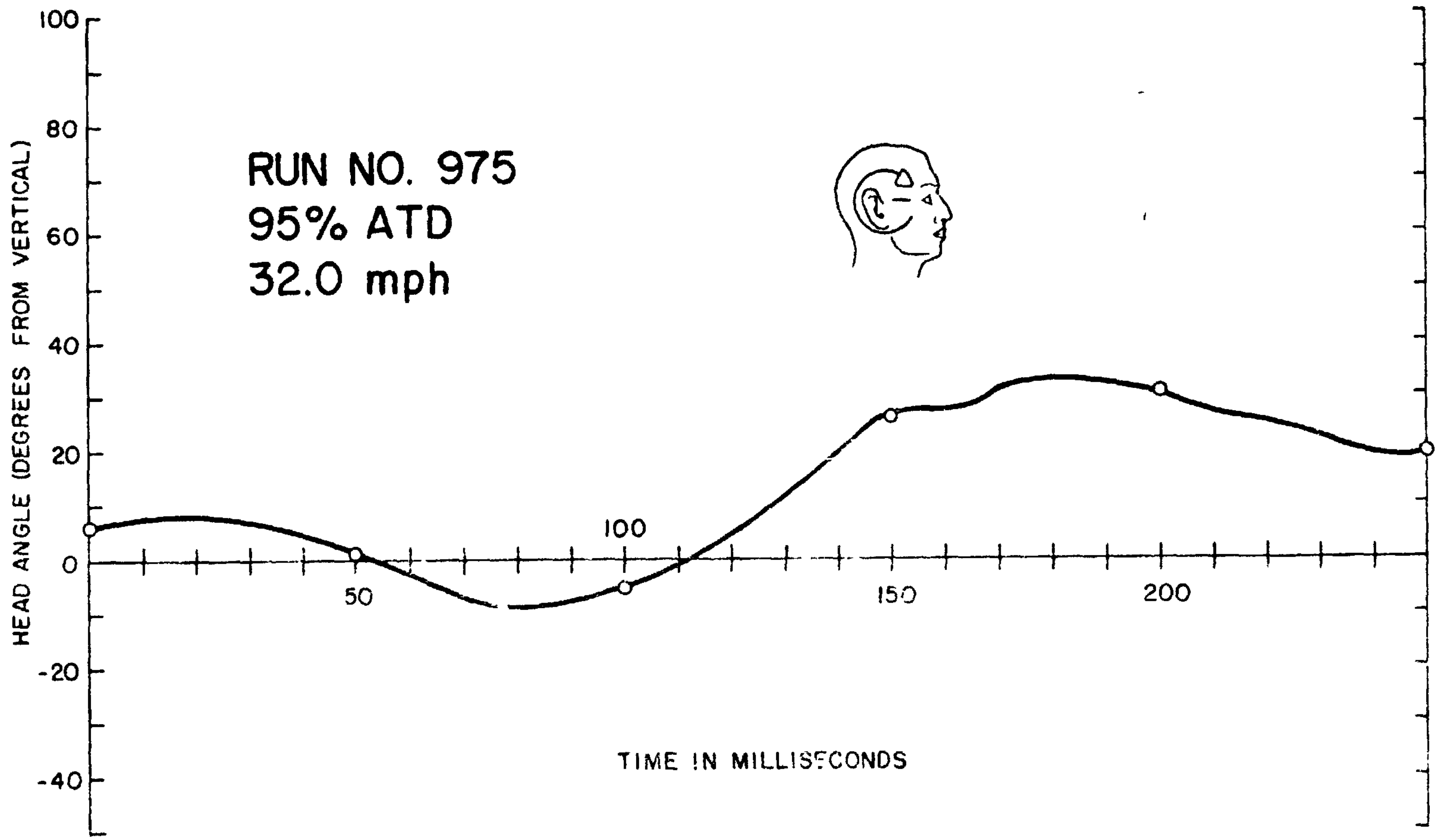


Figure 28. Head Rotation Response

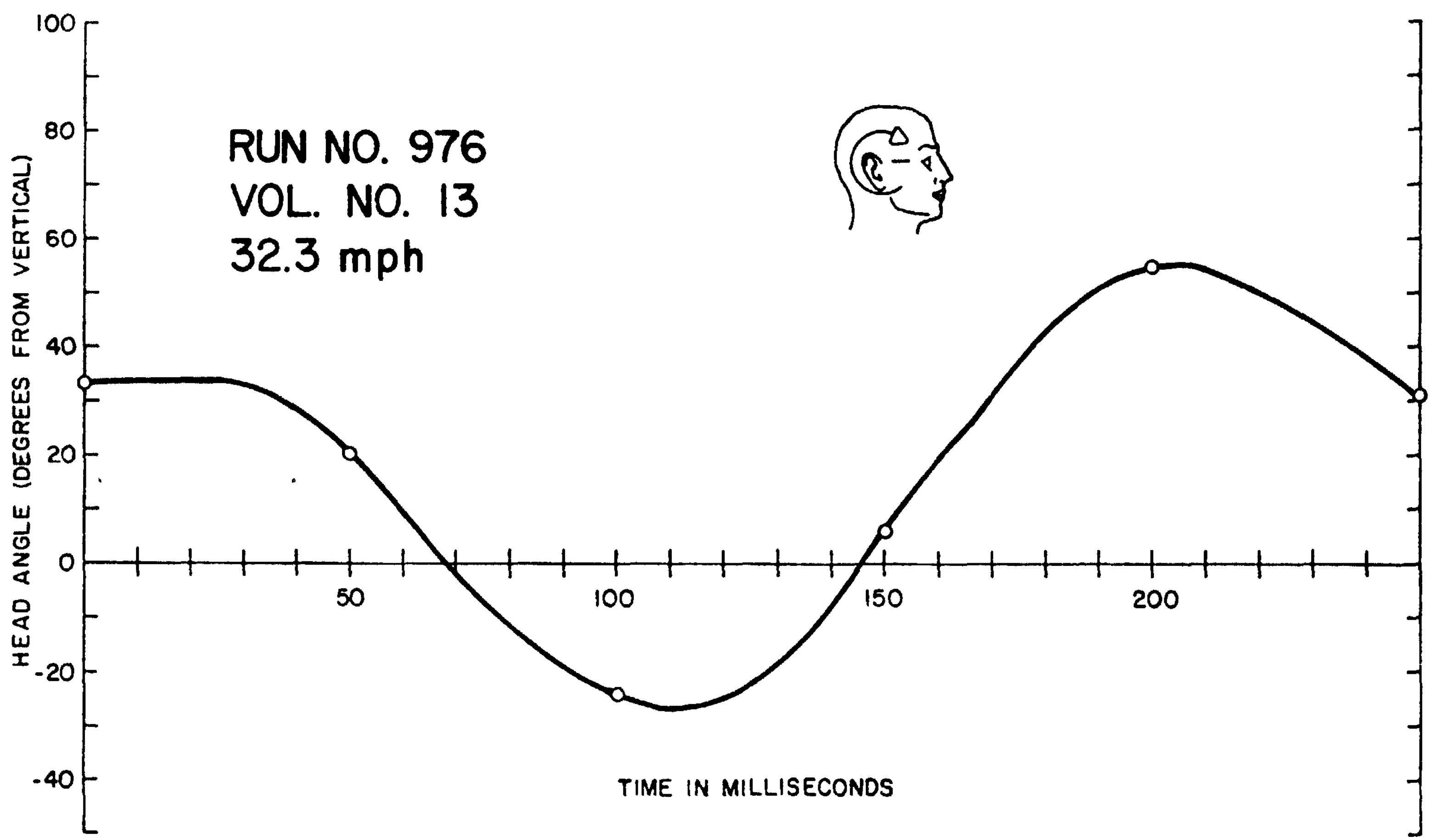


Figure 29. Head Rotation Response

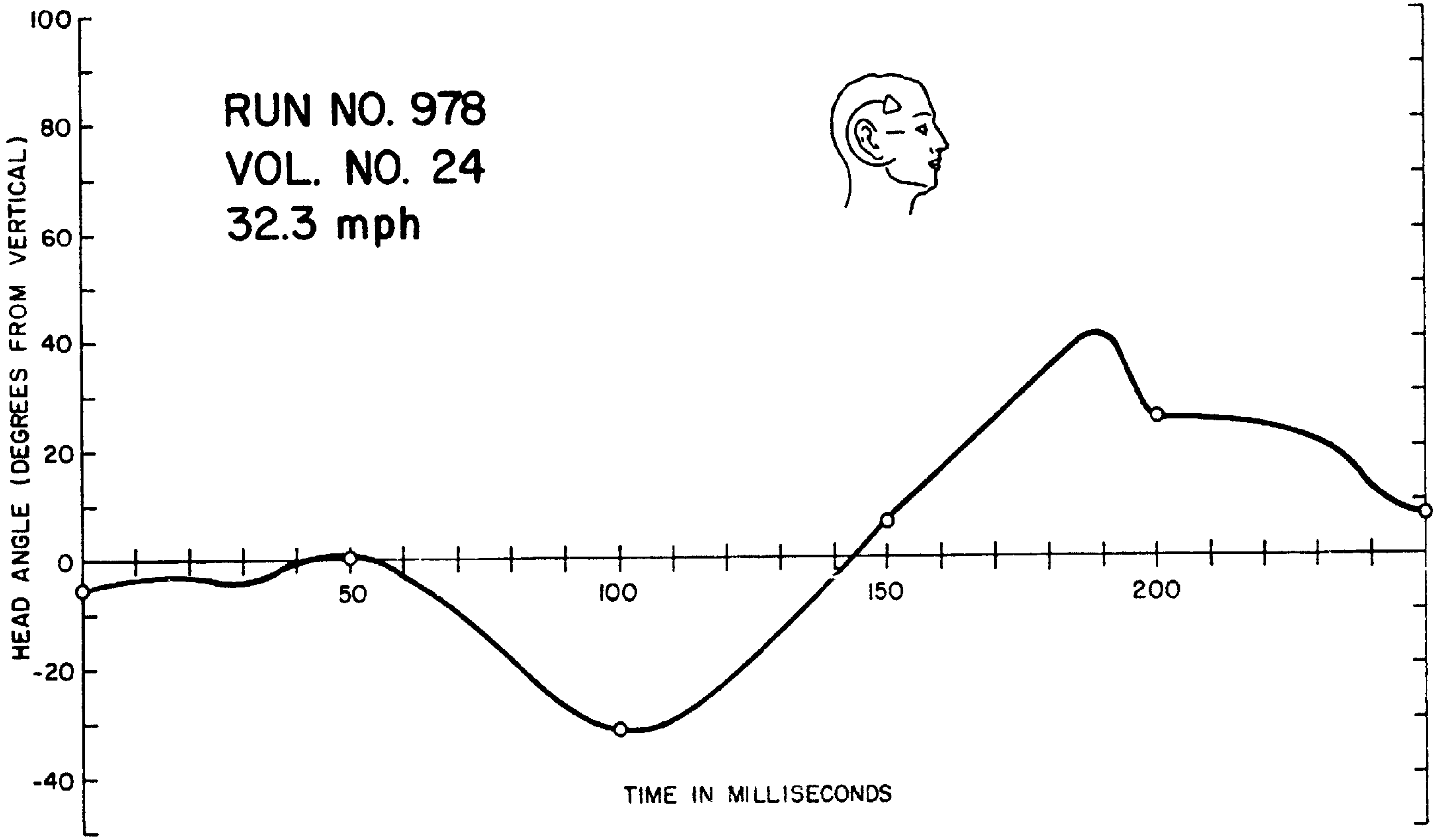


Figure 30. Head Rotation Response

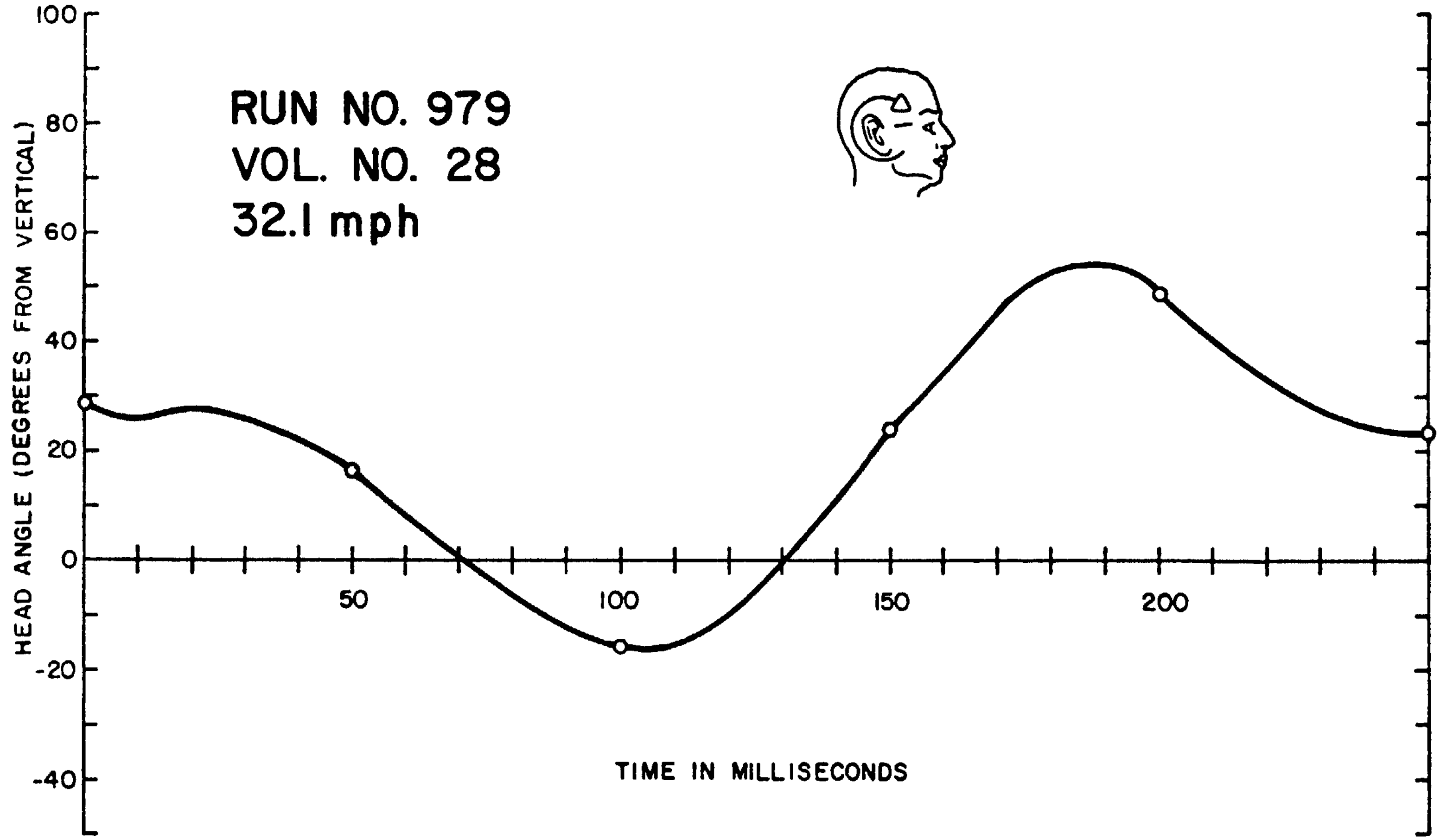


Figure 31. Head Rotation Response

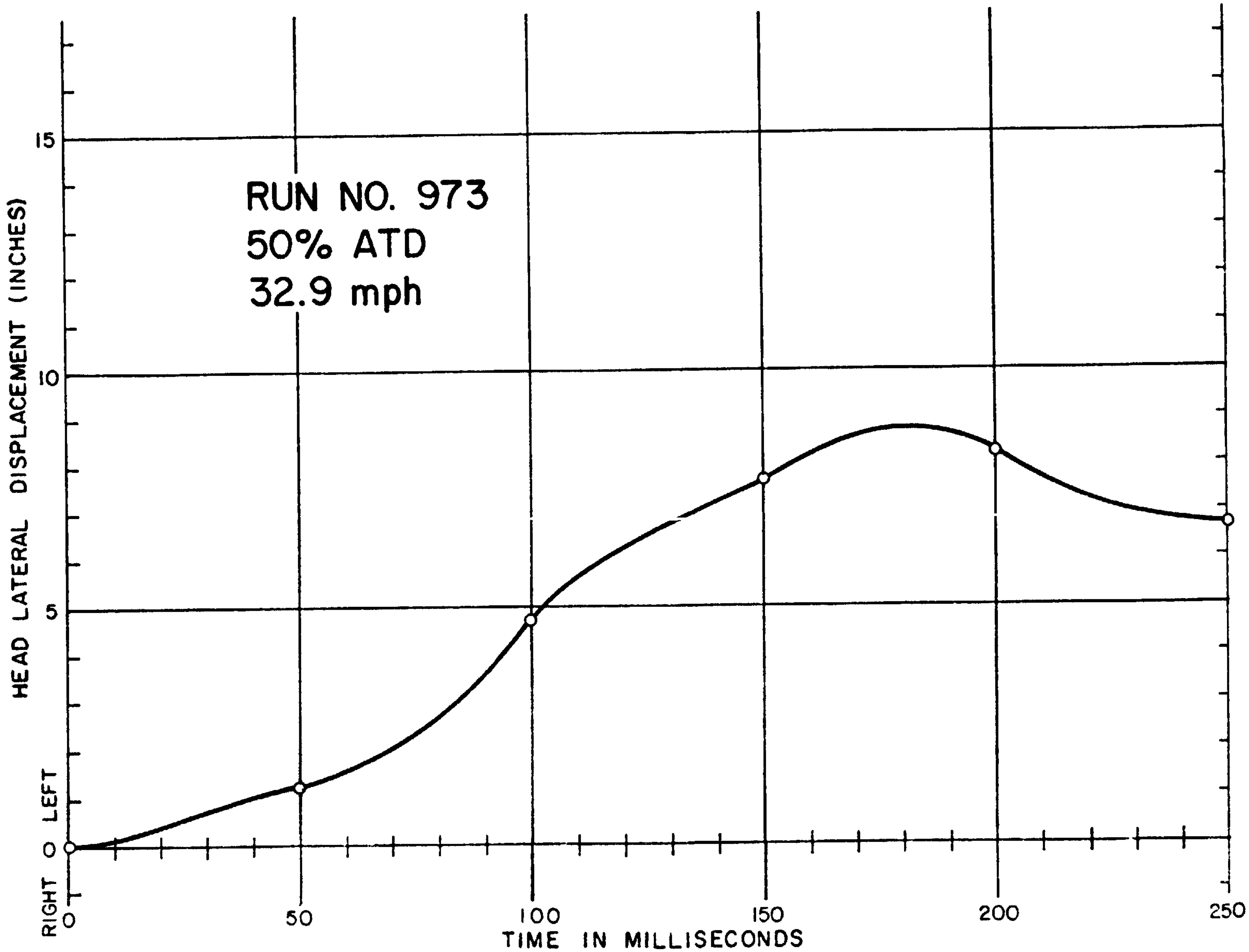


Figure 32. Head Lateral Displacement vs. Time

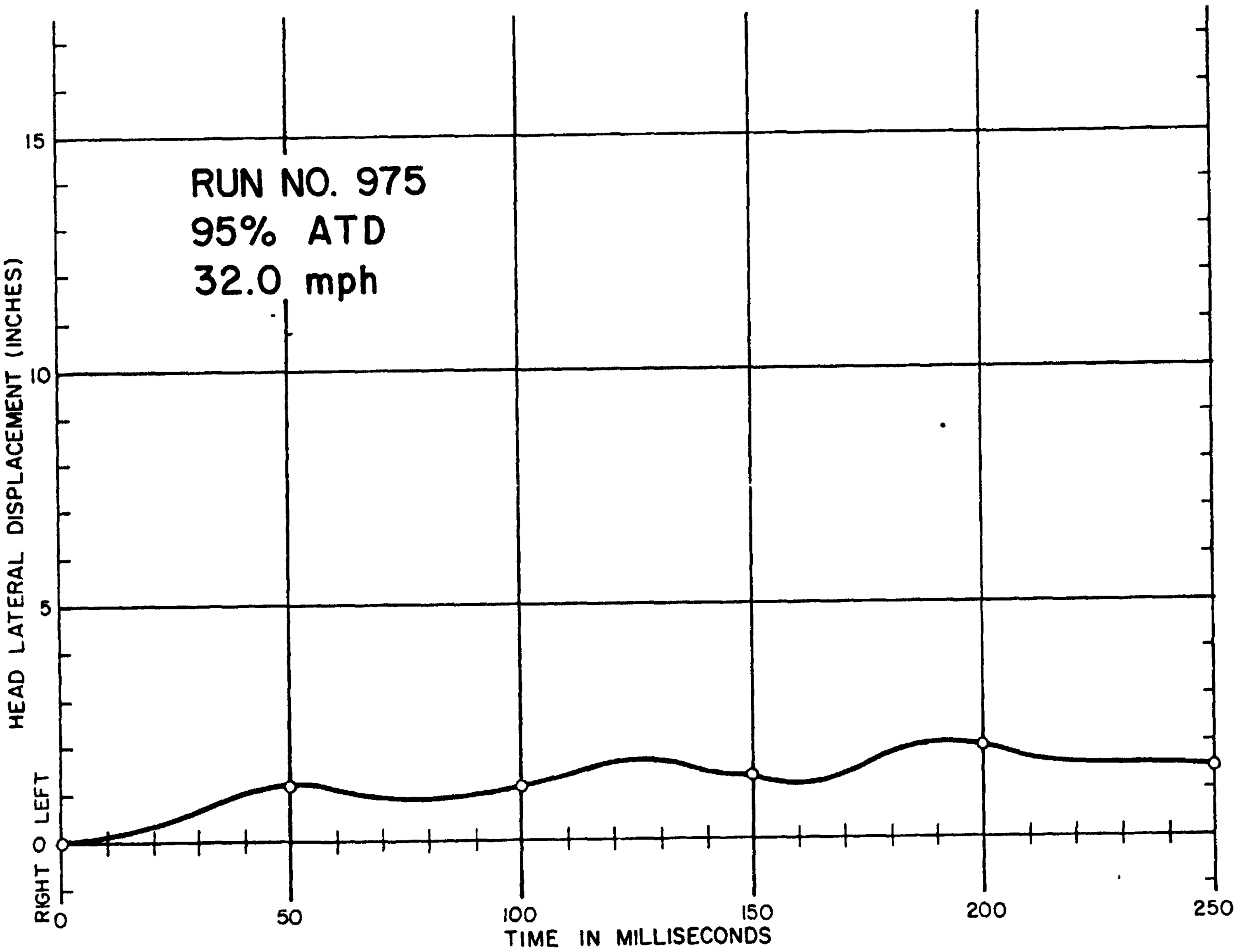


Figure 33. Head Lateral Displacement vs. Time

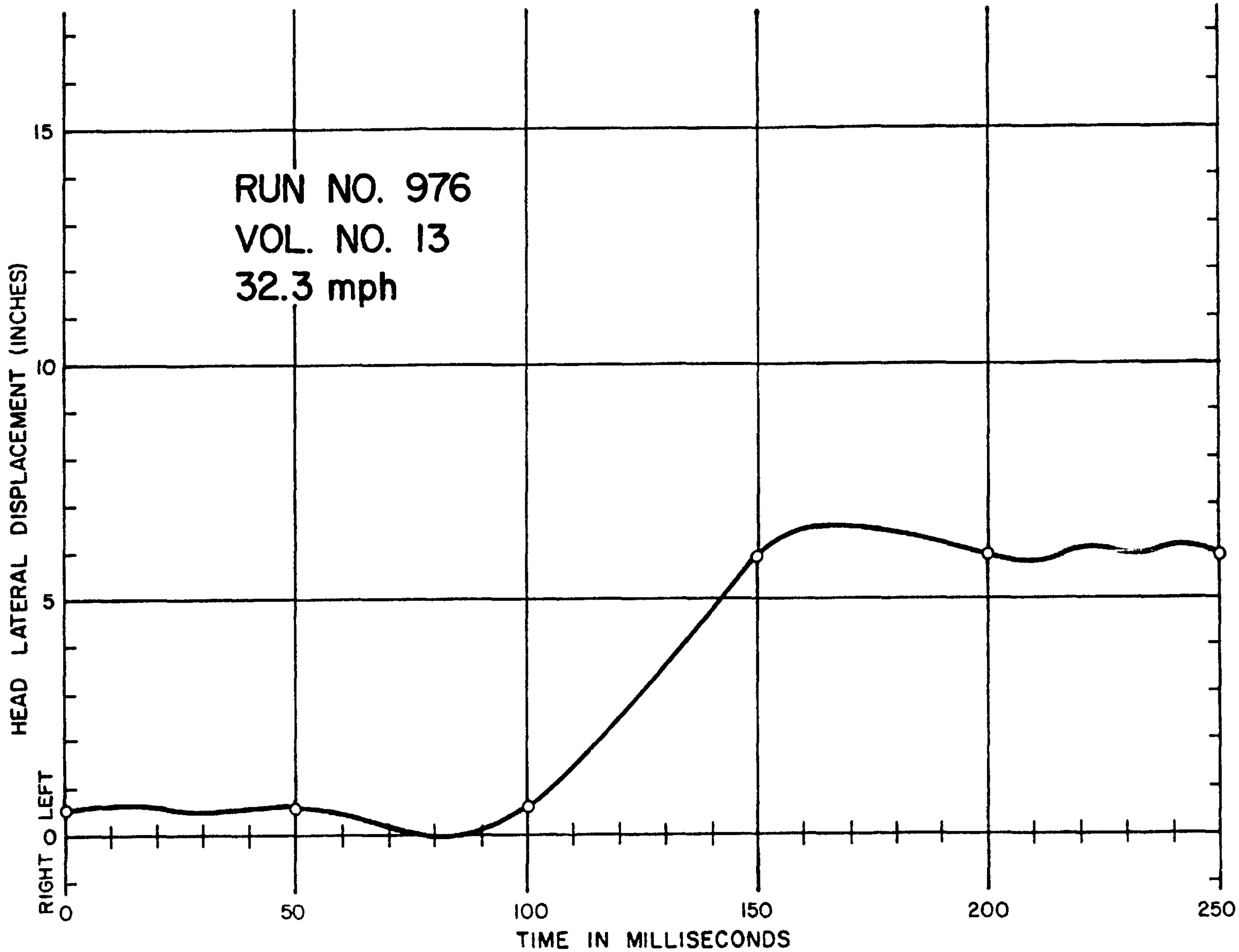


Figure 34. Head Lateral Displacement vs. Time

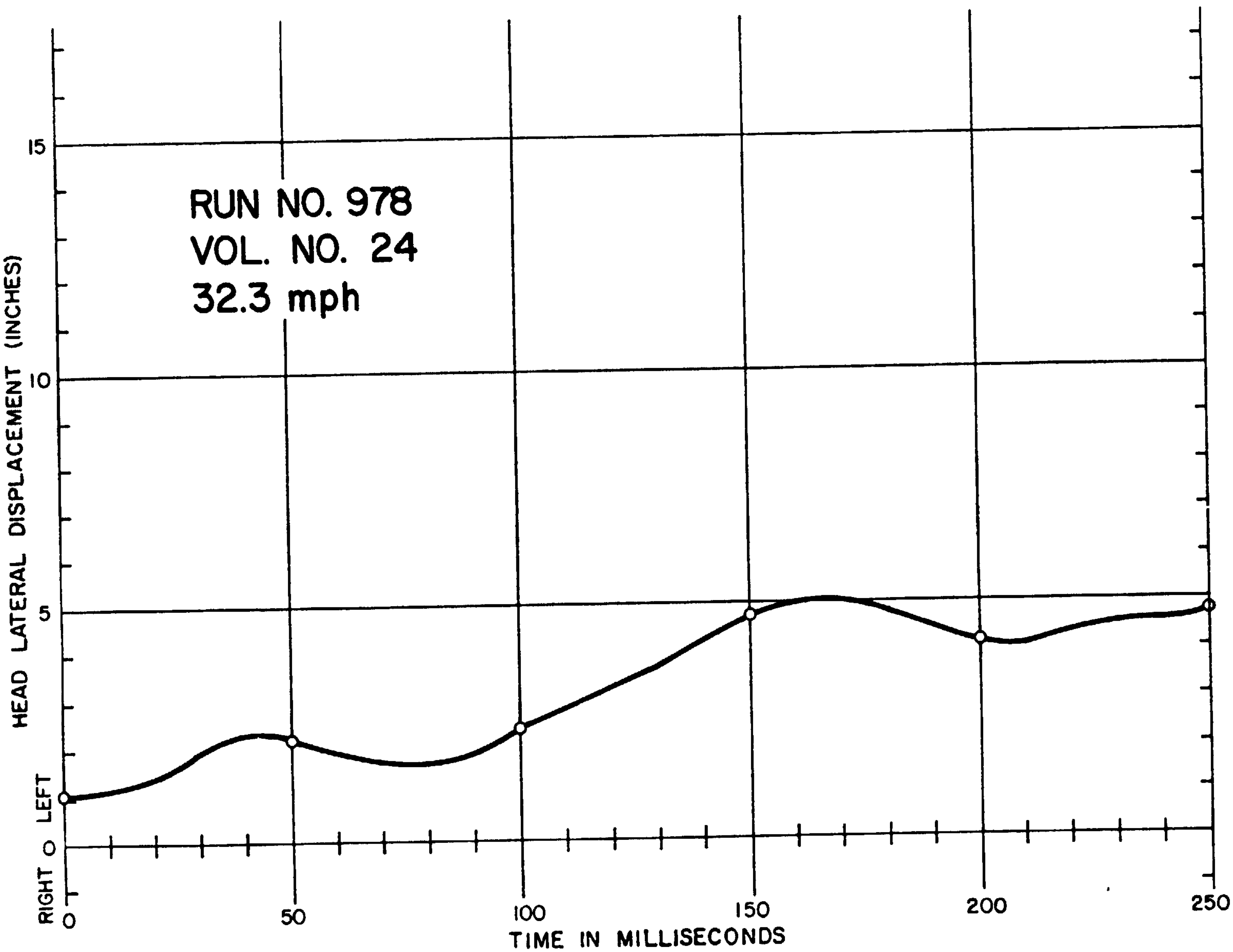


Figure 35. Head Lateral Displacement vs. Time

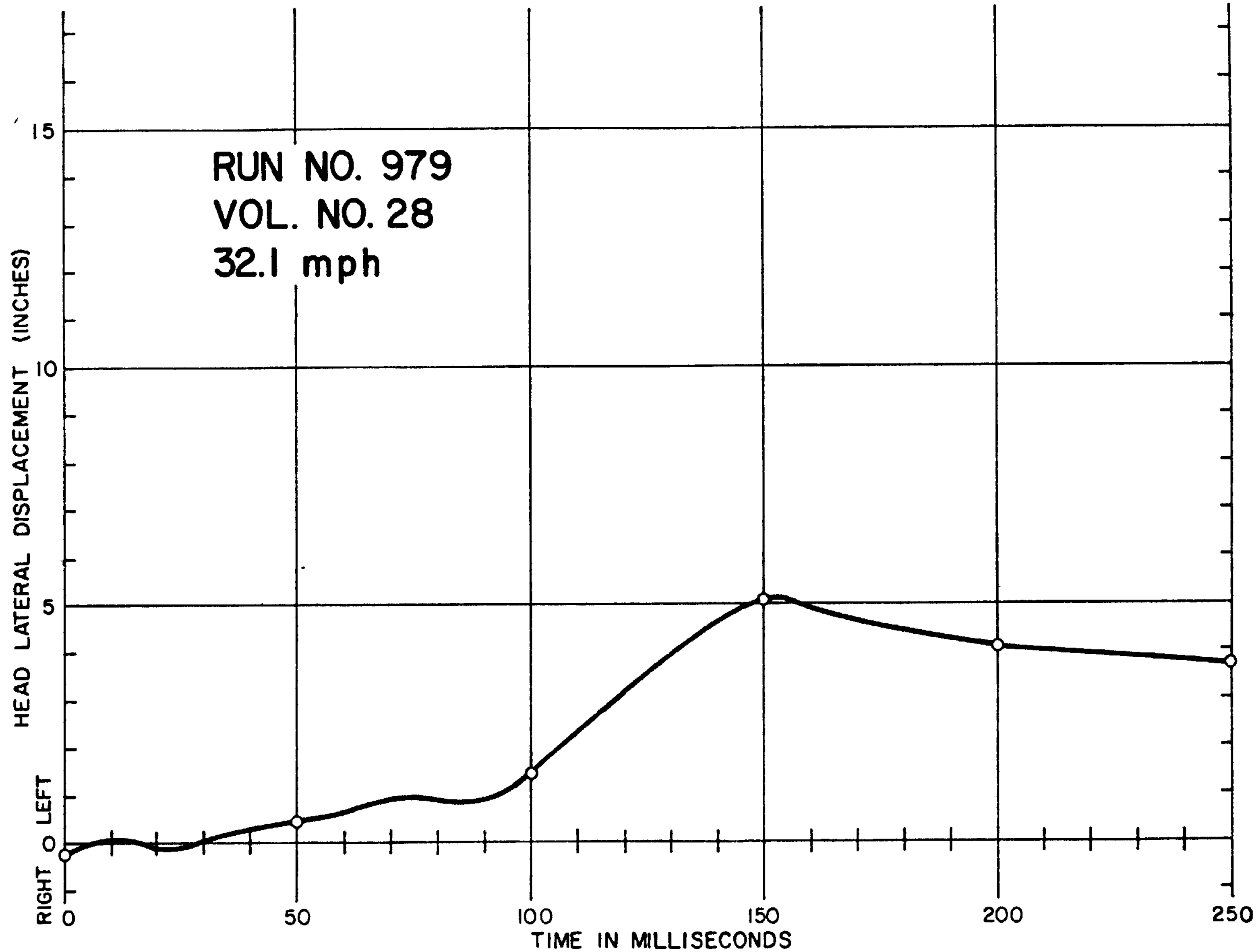


Figure 36. Head Lateral Displacement vs. Time

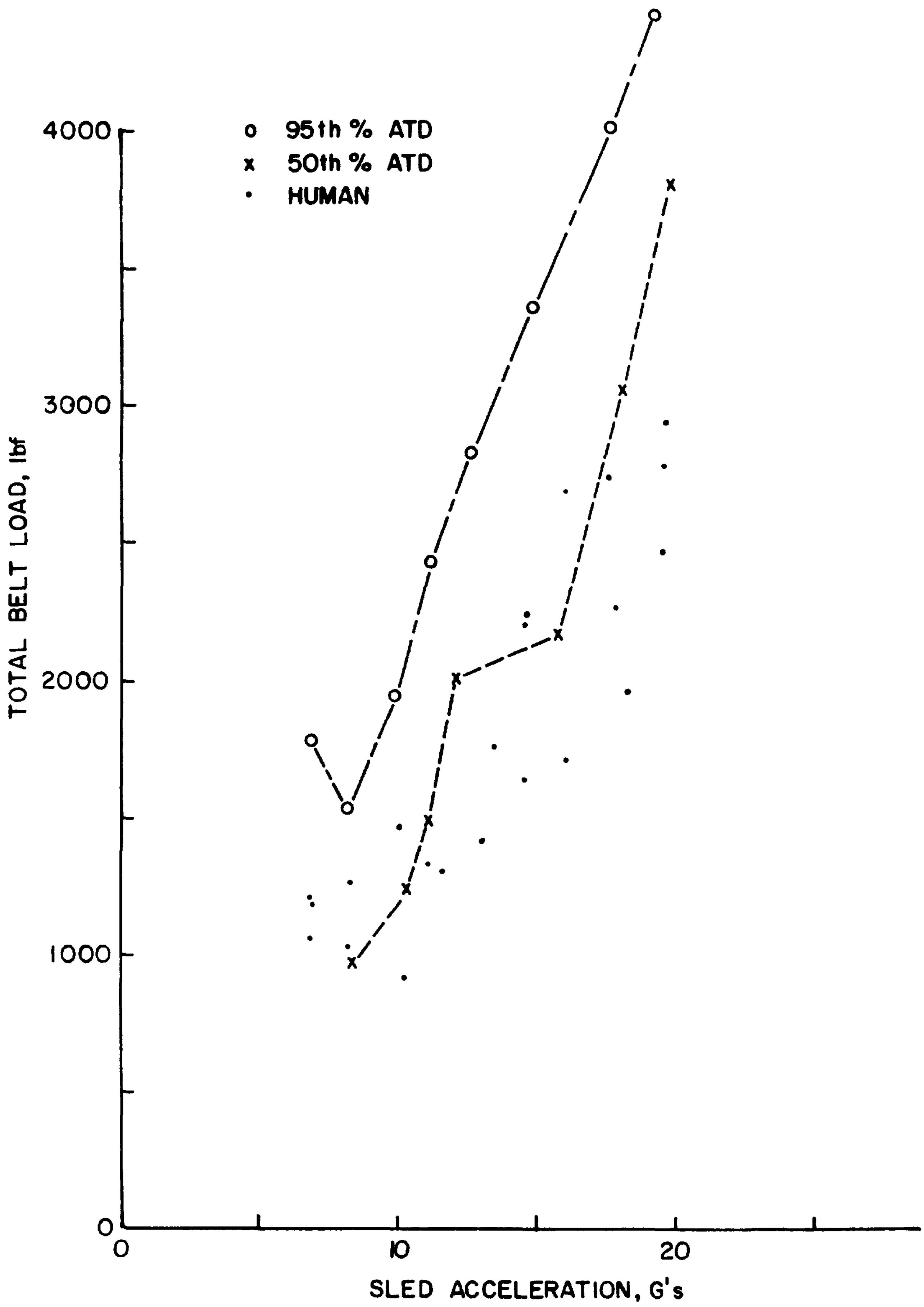


Figure 37. Total Belt Loads vs. Peak Sled Deceleration

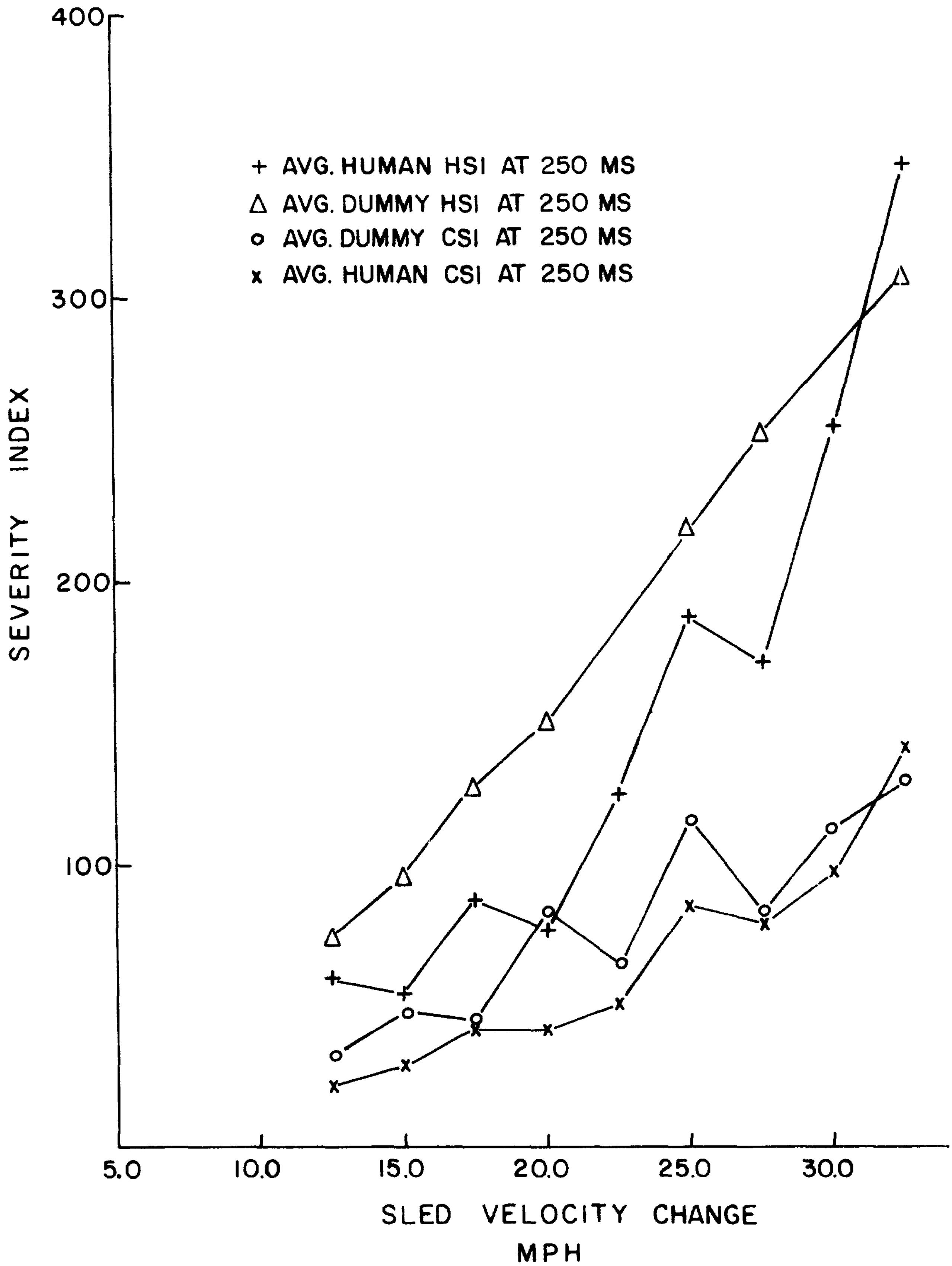


Figure 38. Average Severity Index vs. Sled Velocity Change

ECORDINGS FOR VOLUNTEERS AT VARIOUS VELOCITY CHANGES

Vol. #	1				13				16			
Velocity	10	14.9	22.5	29.3	10	17.7	22.4	32.3	10.1	12.3	25.1	30.2
Pretest 1	140/92	132/80	140/90	144/70	128/80	132/82	132/88	146/78	140/80	140/94	138/82	114/80
Pretest 2	142/80	132/80	142/96			134/94	144/90	146/96	140/88	140/90	144/98	132/88
Post impact	140/80	132/90	140/90	146/70		136/98	142/90	146/86	120/80	134/96	138/88	132/98
Vol. #	21				24				28			
Velocity	9.9	17.6	22.1		10.1	20.5	27.1	32.3	10	20.5	27.6	32.1
Pretest 1	125/80	124/80	130/88		120/74	116/78	126/78	138/76	138/85	128/104	140/100	142/100
Pretest 2		128/90	138/90		124/70	124/72	140/82	138/78		140/96	146/110	148/110
Post impact		132/90	140/96			136/78	142/76	136/80		142/108	146/100	146/108
Vol. #	33				35				36			
Velocity	9.5	12.2			10.1	20.8	18.1		10.2	12.3		
Pretest 1	126/82	132/80			115/75	132/80	130/70		138/76	132/90		
Pretest 2	130/94	134/82				134/68	136/76			134/81		
Post impact	142/94	134/100				142/92	140/76			136/86		
Vol. #	40				41				42			
Velocity	9.9	17.5	24.3	29.3	10.3	15.0	24.4		8.5	15.0		
Pretest 1	140/96	134/90	142/96	146/106	140.80	130/84	136/76		130/80	134/84		
Pretest 2	140/91	132/94	144/98	146/98	138/68	132/80	140/80		140/81	132/90		
Post impact	140/96	132/90	144/91	144/98	140/80	132/82	142/80		140/85	134/84		

TABLE 7

MEDICAL DATA SUMMARY FOR INFLATABAND™ TESTS WITH HUMAN SUBJECTS

Run No.	Vol. No.	Sled Accel. (g)	Sled Vel. (mph)	Main Complaint (See Fig. 8)	ECG Changed
854	42	—	8.5(nom.)	—	N/T
856	1	4.5	10.2	C3, I3	T flat → N/T
857	16	4.5	10.1	K6, C4	N/T
858	40	4.4	9.9	B5, K2	N/T
859	21	4.4	9.9	B7, L6, I5, M5	N/T
860	24	4.6	10.1	B7, E6, K6	T flat → N/T
865	33	4.3	9.5	I7, K6	T flat → N/T
866	13	4.6	10.0	I3, C2, G2	N/T
867	28	4.5	10.0	B2, C2, K2	T flat → N/T
868	35	4.8	10.1	—	N/T
871	36	4.8	10.3	C6, D6, H5, I5	N/T
872	41	4.7	10.3	C4, I4, D3, E3, L3, M3	N/T
884	16	6.8	12.3	C4, K4	N/T
886	36	6.8	12.3	K5, C4	N/T
887	33	6.8	12.2	K2	T flat → N/T
898	1	8.2	14.9	L4, C3	T↓ → N/T
900	42	8.3	15.0	—	N/T
901	41	8.2	14.9	I4, C3	N/T
909	13	10.2	17.7	D2, I2	N/T
913	21	10.0	17.6	D5, C4, E4, G4, J4	T flat → N/T
914	40	10.0	17.5	—	N/T
922	28	11.2	20.5	—	N/T
924	24	11.1	[illegible].5	J6, K2	N/T
925	35	11 6	20.8	—	T↓ → N/T
932	13	13.0	22.4	D2, L2	N/T
934	1	13.5	22.5(nom.)	C3, I3	T flat → N/T
937	21	12.7	22.1	I4, J3, F2, G2	Premature ventricular contraction x 2 preimpact → N/T post-impact
943	41	14.7	24.4	C4, I3, J3	N/T
945	40	14.7	24.3	A2, K2	N/T
946	16	14.7	25.1	B4, C4, I2	N/T
955	24	15.7	27.1	—	T flat → N/T
957	35	16.1	28.2	C2	T flat → N/T
958	28	16.0	27.6	—	Premature ventricular contraction x 3 post-impact → N/T
966	16	18.3	30.2	C4, J4, I3	N/T
968	40	17.6	29.3	K2	N/T
969	1	17.8	29.3	C3, D2, E2, F2. J2	T flat → N/T
976	13	19.6	32.3	C2, L2	N/T
978	24	19.7	32.3	B2, C2, R2	N/T
979	28	19.6	32.1	—	N/T

T ↓ = T wave inversion
→ N/T = Returned to normal/trace

V. DISCUSSION

A. Operational Problems

The major problem of significance was created by the passage of metal debris from the inflator into the band segments. On three occasions (Test Nos. 841, 866 and 895), particles perforated the band material. To reduce the hazard of the volunteer being injured by penetrating particles, several measures were undertaken.

As a first attempt at retaining large pieces of material within the generator, a deformation cavity was created to "catch" the rupture disc. Smaller particles (less than 3mm x 3mm) received special consideration as they would not be effectively retained in the inflator 100 percent of the time without major modifications. To protect against small particles, chamois cloth was inserted in the areas of potential impingement on the arms and abdomen of the volunteers. In addition, the shoulder/lap band was sewn with double layer material in the area where the gas is vented into the band segments.

In none of the three observed cases of band penetration was the performance of the system degradated or a volunteer injured.

B. Seat Deterioration

As the program did not have available an adequate supply of seats, it was necessary to utilize the same seat in a number of tests. To minimize the influence on system performance as created by seat deterioration, a control program was initiated to keep a history on the deformation characteristics of each seat used more than once. Following each test, the seat pan deflection from a reference point was measured in response to the application of a consistent load. Seats were discarded when measurements indicated more than one-half inch of change from the initial condition. For the 30 mph (48.3 kph) and 32.5 mph (52.3 kph) test series, seats were used only once.

Seat back deformation was periodically checked with an automatic protractor. The angular deviation was not more than two degrees. Seat back deviation was probably minimized by the restricting of rearward deflection upon occupant rebound. Between the seat and the headrest, a collapsible styrofoam and Ensolite pad was inserted to absorb rebound energy and limit rearward displacement.

C. Dummy/Human Performance

The performance of the anthropometric dummies used for the production testing was satisfactory. Component problems were minimal with the only failure being the neck element of Humanoid Dummy S/N 182. The torso of both 50th percentile dummies were disassembled during the course of the program for reworking shoulder and arm joints which were prone to gall after minor use. The problem appears to be caused by a joint material incompatibility.

Prior to its usage in a test, the dummy's joints were checked for operation and adjustment. Each limb joint was set for the standard one g threshold when extended horizontally. Because of the limited joint resistance, several distinct differences were observed between human and dummy kinematic response as listed below:

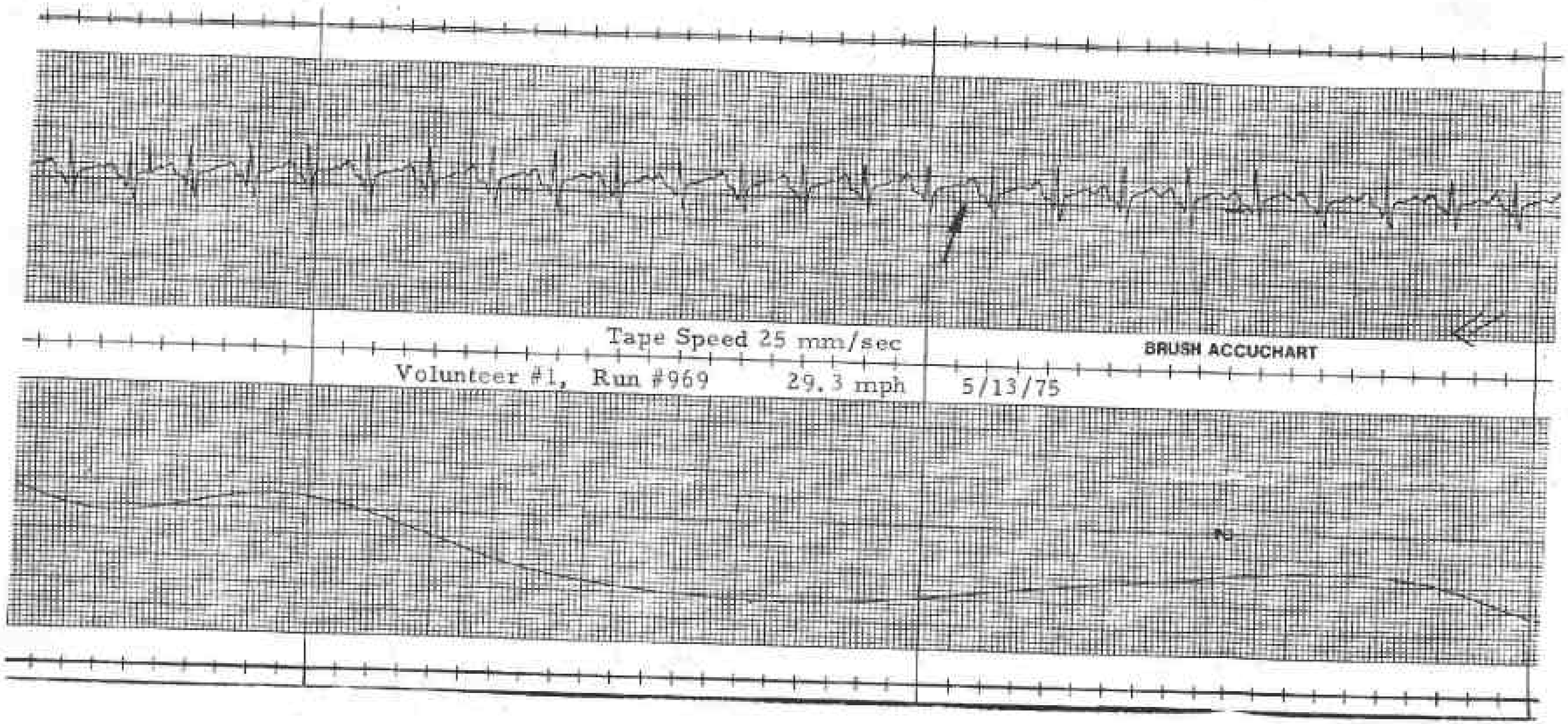
1. Torso rotation. Particularly with the 50th percentile ATD, the torso rotates about the shoulder band. During impact, the left shoulder is not braced sufficiently to counteract the moment created by the band reaction loading on the right shoulder.

2. Lateral displacement. Because of torso rotation and the reflection of the head as it rebounds from the band, the dummies rebound to the left of the seat center line. Review of Figures 32 through 36 showing lateral head displacement for the 32.5 mph (52.3 kph) series indicate that the lateral excursions were bounded by the dummies: the extreme being that of the 50th percentile dummy and the minimal excursion being that of the 95th percentile dummy.

3. Combined belt loads. The data summarized in Figure 37 indicate that the load transmitting capacity of the legs for both dummy types is much less than that of the volunteer. This is also verified by the toe pan loads tabulated in Table 5.

4. Rebound deceleration. Review of the computer plots presented in Appendix E indicate that the dummies experience large deceleration values on rebound. Above 27.5 mph (44.3 kph), the differences in rebound levels between human and dummies are less pronounced contributing to the convergence of the human and dummy parameters plotted in Figure 39. These results indicate the existence of a threshold above the 32-34 mph (51.5 - 54.7 kph) region in which the effect of muscle tone is not as significant as it is at the lower impact severities.

The review of the photographic records reveal that subjectively those volunteers similar in size and weight to the 95th percentile dummy exhibit similar kinematic responses. In addition, it appears that the Inflataband™ is best suited for the 95th percentile occupant as it more effectively controls the kinematics of impact. As observed in the 32.5 mph (52.3 kph) series, Figures 28 and 33, head flexion (as well as rate of change in head angular position) and lateral displacement are minimal, the reason being that the chin overides the deployed band providing head



Inverted "T" Waves after Impact

FIGURE 39

support. For smaller occupants, the head is pushed to the left as the body begins to respond to the impact; the chin slides down and then into the band producing head rotation and allowing greater head flexion.

Unlike the dummies, whose response was reasonably repeatable and predictable, each human reacted differently to impact. Some displayed better riding abilities than others where the abilities are functions of subject experience, coordination, mental attitude, muscular build, etc. Success in extrapolating impact severities for a given volunteer was marginal probably because of the "volunteer learning curve." After each ride, the volunteer may learn something to improve his next ride or depending on his reaction, he may become more apprehensive. Either result affects riding ability.

For the reasons discussed above, the comparison of human/dummy performance would have been improved had a volunteer matching dummy anthropometrics been exposed to impacts at each severity level since no volunteer participated in more than three (3) production tests (Table 8).

D. Restraint System Performance

The performance of Inflataband™ in providing protection for occupants involved in direct frontal impacts simulated in the laboratory is entirely adequate. In no case did the observed severity indicators (HSI, CSI, HIC) approach or exceed the existing human tolerance levels for these indicators. Injuries to the human subjects were minimal consisting primarily of mild erythema to the face and neck; at the higher impact severities, some residual neck soreness was documented as noted in the Medical Section of this report. Impact forces on the upper torso and abdomen were effectively distributed without major discomfort. Some volunteers, however, depending on their position (slouching or high in the seat) would receive a sufficient blow to knock their breath away momentarily. The control of head rotation and flexion by the Inflataband™ appears to be dependent upon the initial amount of chin overide of the shoulder band and initial head position.

In every test, the Inflataband™ was fully deployed before the subject began to translate forward. The duration of deployment is short (7-8 msec after impact detection) making the system advantageous for small cars. Not only does deployment occur at a rapid rate, but the very act of deployment also restrains the occupant due to the foreshortening of the bands during inflation. Consequently, the occupant utilizes the available stroke and vehicle ride down more efficiently than would a conventional belted restraint system. Submarining was minimal and observed primarily with the 95th percentile dummy.

Table 8

Subject Run Number Matrix

Subject No.	Sled Δv, mph/kph								
	12.5/30.1	15.0/24.2	17.5/28.2	20.0/32.2	22.5/36.2	25.0/40.3	27.5/44.3	30.0/48.3	32.5/52.3
01		898			934			969	
13			909		932				976
16	884					946		966	
21			913		937				
24				924			955		978
28				922			958		979
33	887								
35				925			957		
36	886								
40			914			945		968	
41		901				943			
42		900							
50th% Dummy	881	895	906	918	929	940	952	963	973
95th% Dummy	882	897	908	920	931	942	954	965	975

A significant portion of the total Head Severity Index at the higher levels (20 to 25% for the human riding at 32.5 mph) was accumulated during rebound. Reduction in the severity response could be obtained by reducing the amount of impact energy stored in the system. The utilization of orficies (in the form of band material porosity for example) to throttle system gases or load absorbers at the attachment points would be two approaches both of which would result in increasing the required occupant deceleration distance or stroke.

As a secondary consideration, volunteers repeatedly expressed concern for not having a structure against which to brace the arms. The integration of a collapsible steering column or instrument panel would have been advantageous solely to increase the occupant's mechanical advantage in bracing against the impact. The Inflataband™ as tested works well; however, the use of selected subsystems could perhaps enhance the performance to an even greater extent.

E. Medical Observations

Hearing. All volunteers had noise attenuation ear plugs placed in their external ear canals during their run. All volunteers, with only two exceptions stated that they either had not heard the sound of the pyrotechnic device which inflated the belt, or that the sound was so insignificant as not to be important. One volunteer (#21) in his indoctrination run stated that the report of the pyrotechnic device was "loud and distracting." In two subsequent runs at 17.6 mph (28.3 kph) and 22.1 mph (35.6 kph), the same volunteer had no complaint about the noise.

Blood Pressure. All blood pressure recordings taken showed a minimal elevation of both systolic and diastolic pressure coincident with sitting down in the buck. A second pretest B/P normally recorded at 4 minutes before sled release showed a small rise in pressure apparently associated with the increase in tension as the impact approached. Almost without exception, the post-test B/P returned to early pre-impact levels. No sustained pathological B/P levels were recorded although in volunteer #28, diastolic pressures above 100 mm Hg were transiently recorded both pre- and post-impact at velocities of 20.5 mph (33.0 kph), 27.6 mph (44.4 kph) and 32.1 mph (51.7 kph).

In all individuals tested on multiple occasions, there was a tendency for the blood pressure to be higher as the test speed rose and to be highest in the run with the highest velocity change. On four occasions however, the B/P on the second run was lower than on the first test. It is possible that having overcome the initial apprehension of the unknown with the first test, the second was associated with less tension for these four individuals (See Table 6).

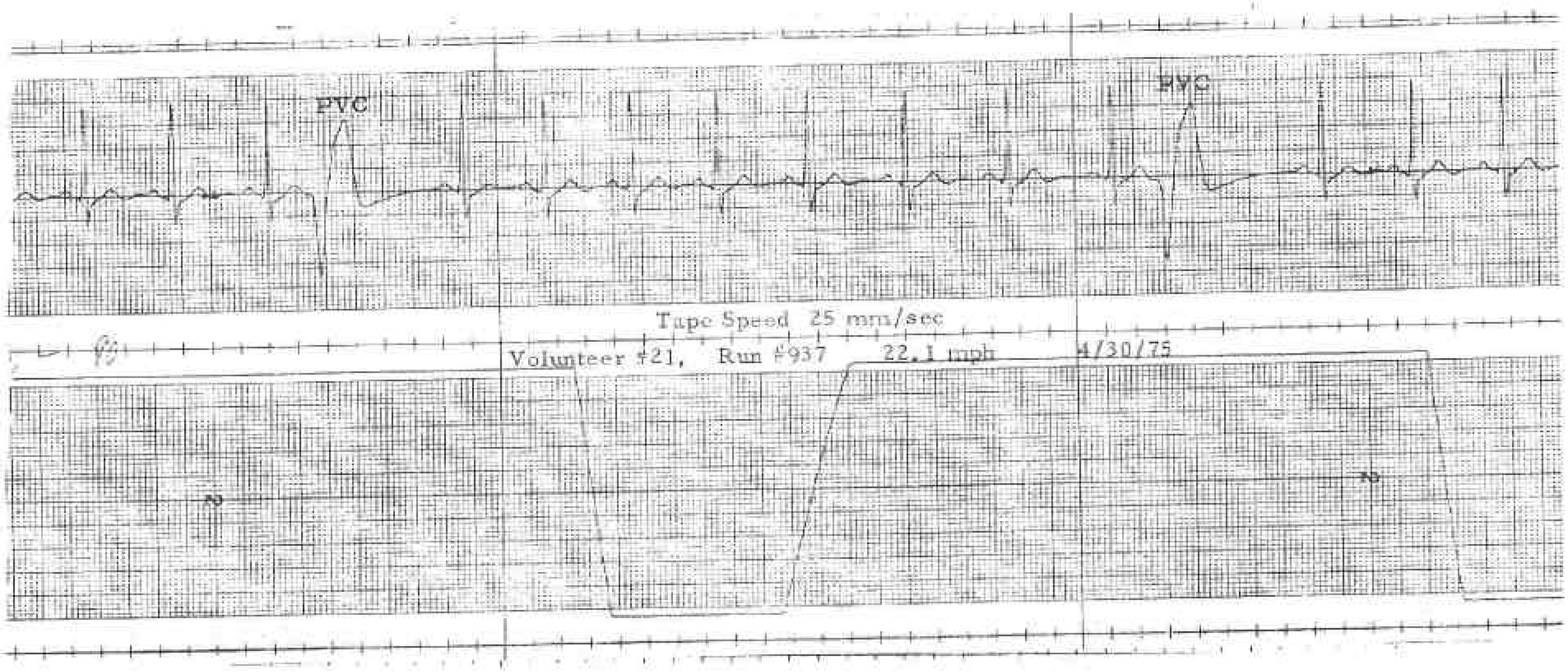
Pulse Rate. All subjects had an increase in pulse rate as the anticipated impact approached. No pathological elevations occurred during the time of the test and all rates returned to pre-test levels after impact. Increasing sled velocity and/or acceleration influenced P.R. so that the higher the anticipated test velocity, the higher the P.R. rose to a maximum P.R. in one volunteer of 166 bpm at 32.3 mph (51.8 kph).

ECG. No pathologically significant ECG abnormalities could be demonstrated in any volunteer during the course of these tests. The most frequent change in ECG pattern encountered was either a flattening or an actual inversion of the "T" wave. This occurred within 1 or 2 seconds post impact, persisted for approximately 5-10 seconds, and returned to normal before the ECG electrodes were disconnected. Flattening of the "T" wave occurred in ten subjects while inversion of the "T" wave occurred in two (See Table 7). These changes were neither velocity nor acceleration connected. See accompanying ECG tracing (Figure 39) for an example of "T" wave inversion in Subject #1.

The "T" wave flattening and inversion noted in other subjects were all stress induced and reverted to normal patterns within a few seconds post-impact. Obviously, they were not produced by any organic heart changes. They were completely benign in nature.

In two instances, premature ventricular contractions (PVC) occurred. One of these occurred in the pre-impact period in volunteer #21, Run #937 at 22.1 mph (35.8 kph) and consisted of 2 PVC (Figure 40). The other occurred in the post impact period in volunteer #35, Run #957 at 28.2 mph (45.4 kph) and consisted of 3 PVC. In both instances there was no coupling of these beats in any pattern and in both instances normal ECG pattern was quickly restored. These aberrant heart rhythms were without organic basis, were benign in nature, and represented no significant heart conduction abnormalities.

Trauma. Main complaint (Table 7) was derived from the physical symptom survey (Figure 18) filled out by the test subject immediately post-impact. Nine individuals indicated they had no symptoms whatsoever. These individuals had been tested at velocity changes ranging from 8.5 mph (13.7 kph) to 32.1 mph (51.7 kph). The main complaints of subjects who listed symptoms in the immediate post-impact period varied from sensations of mild pressure to those who listed moderate pain. Only three individuals recorded moderate pain as one of their symptoms and each of these occurred in the indoctrination runs at 10.1 mph (16.3 kph) or less. Five individuals in the group of indoctrination runs listed mild pressure in various areas as their main complaint. This compares with only one individual in all subsequent runs who listed any complaint as severe as mild pressure.



Premature Ventricular Contractions in Pre-impact Period

FIGURE 40

None of the listed complaints (mild as they were) was in any way associated with the decelerative force. Instead the pattern of complaint seems to be indicative of contact with the expanding inflataband as a slap of bag against body area involved or as pressure produced by the expanding bag against body area. The areas of complaint most frequently named were the right side of the neck and the lower part of the right face (25 instances); the upper right chest, shoulder and base of the neck (10 instances); and the lower abdomen and base of the right groin and thigh (29 instances). In several instances (five volunteers) the left forearm was slapped by the expanding Inflataband.

Physical Findings. These were derived by actual observation post-impact and were recorded immediately post-impact by the examining physician. As could be anticipated from the results recorded in the section "main complaints," erythema, involving the base of the right neck, the lower face (right) and the right clavicular region leads all other findings. Erythema of the abdomen was minor in extent, was found only occasionally and occurred less frequently than erythema of the base of the right thigh. This lower incidence of erythema of the abdomen could have been caused by the wearing of the chamois over the lower chest and abdomen by each volunteer. The erythema noted in each of these areas was minimal in degree and probably disappeared within an hour or two post-impact although these volunteers were not observed for that lengthy period. It was not unanticipated that the erythema was most marked in the areas listed. This coincided with the "main complaints" listed by the volunteers and was, of course, the body areas mainly subjected to slapping contact by the expanding Inflataband.

One volunteer (#1 at 14.9 mph/24 kph) had ecchymosis develop because of the severity of bag contact on the base of the right thigh and volunteer #24 at 20.5 mph (33 kph) developed ecchymosis of the left forearm due to contact (Figure 41). Because we noted in our motion picture review that in certain individuals the expanding Inflataband struck the left forearm, we began to caution all volunteers to brace their left arm at a position somewhat wider from the wide than was true on the right and this alleviated this problem. In order to minimize slapping contact of the Inflataband with the base of the right thigh, a small styrofoam pad was placed at this point beneath the pajamas of each volunteer. This decreased the complaints.

Two volunteers (#28 and #36) stated immediately post-impact that they had had the breath knocked out of them by the impact deceleration. This occurred in a ride at 12.3 mph (19.8 kph) (#36) and in volunteer #28 in a ride at 27.6 mph (44.4 kph). Three volunteers stated either that they were "shook up" or "saw stars." In volunteer #36 this occurred at 12.3 mph (19.8 kph) while volunteer #21 saw stars at 17.6 mph (28.3 kph) and volunteer #40 was stunned for a moment at 29.3 mph (47.2 kph).

FIGURE 41. Ecchymosis Left Forearm

The only significant complaint which surfaced after the volunteer had left the impact facility and was reported on the Subjective Report (Figure 19) was that of <u>stiff neck</u>. Volunteer #1, after a ride at 29.3 mph (47.2 kph) stated he had developed a stiff neck within 24 hours of the test and that it remained mildly stiff for 72 hours and gradually resolved. Volunteer #13 developed a sore neck approximately 5-6 hours after impact at 32.3 mph (52 kph). Within 3 hours he found he couldn't turn his head to the right without pain. In 72 hours he found he had only residual soreness in turning his head to the right. Volunteer #16 who was impacted at 30.2 mph (48.6 kph) developed onset of neck pain within 24 hours of impact and this continued for 48 hours. He also developed a bruise of the right cheek which lasted for 3 days. All three volunteers had remission of all neck symptoms within 96 hours after impact.

APPENDIX A

System Activation Methodology

System Activation Methodology

The firing system consisted of two independent firing circuits, one primary circuit and one secondary or backup circuit. Both systems used proximity switches that were triggered as the sled passed a specific location in its approach to the programmer. The primary firing circuit was located at the sled control console, and the secondary circuit was mounted on board the sled.

The primary circuit had a circuit to visually indicate power source voltage. The visual display was a LED that would not function unless the battery voltage was greater than 11.5 volts. Also a LED was used to indicate proximity switch status so that the operation and connection of the switch could be verified before each test. A resistor divider circuit was used to give a one volt output when the firing switch was closed for recording purposes (system function). The output of the primary circuit was shorted until 30 seconds before test to preclude inadvertent activation of the system.

The secondary circuit utilized only one LED as an indication of both switch closure and battery voltage. In order to isolate the operation of each circuit, stirring diodes were used as shown in Figure A-1.

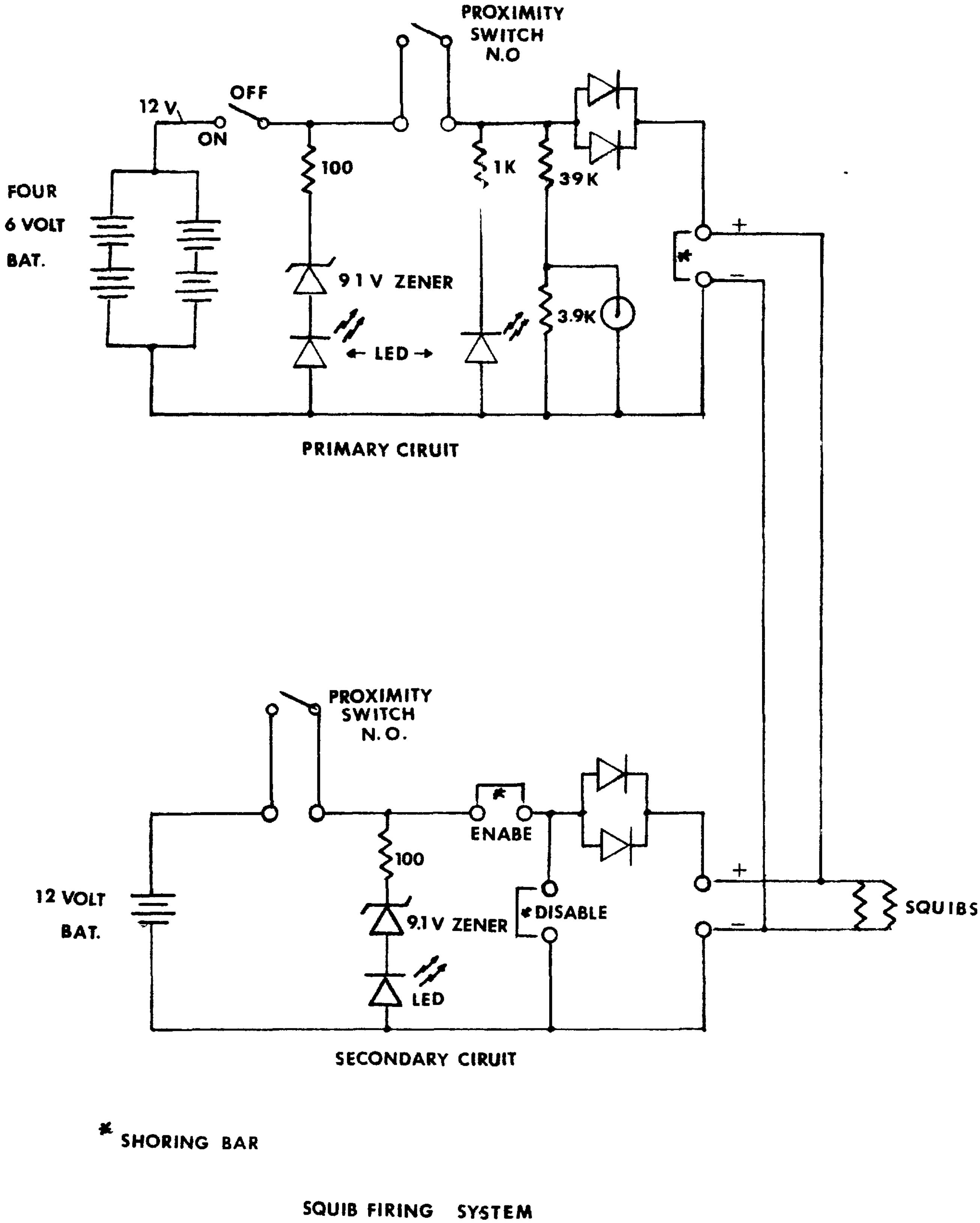


Figure A-1. Squib Firing System

APPENDIX B

Explanation of Risk Potential and Informed Consent Form

Explanation to Volunteers of Risk Potential

You have volunteered to participate in a program designed to test automobile seat belt restraints by the Department of Bioengineering and the Division of Automotive Research at SwRI. These seat belts are known as Inflatabands and look very much like the belts in your own vehicle with the lap and over-the-shoulder components. These belts are designed so that upon impact a sensor triggers a pyrotechnic device which releases gas into each of the two belt components thereby inflating them and producing a cushioning as well as restraining effect. This restraint system has previously been tested with dummies but has never previously been tested with humans. It is our plan to start this test by giving the volunteers an indoctrination ride at 8.5 mph (13.7 kph) to acquaint them with the sensations they may experience in the evaluation tests later on. The evaluation tests will commence at a total velocity change of 12.5 mph (20.1 kph) and increase the velocity in increments of 2.5 mph (4.0 kph) until we achieve 30 mph (48.3 kph). In every instance as we increase the velocity by 2.5 mph (4 kph), the first two tests at the new speed will be conducted with anthropometric dummies as subjects. Only after we determine how they have come through the test and know here's no possibility of danger will the human volunteer be permitted to be tested at the new velocity.

In every test that we run at any velocity we will use a back up restraint system which will serve to keep you from being injured. This restraint system was used for human volunteers at Naval Air Development Center, U.S. Naval Base, Philadelphia, Pennsylvania in testing the effectiveness of another type of energy absorbing seat belt restraint. It is placed around you in such a way as to prevent you from being thrown against the interior of the sled or being ejected from the sled if the Inflataband fails for any reason.

In testing seat belt restraints of the 3-point type (lap and over-the-shoulder components) the main concerns in regard to injury production are:

1. Failure of the system and injury by impact against sled interior or being ejected. This cannot occur in this instance because of the back up restraint system.

2. Abrasions, contusions and lacerations produced by the belts in contact with your body. All belt placement will be checked by the team prior to sled release to insure proper placement. If necessary additional padding or clothing will be worn to minimize this possibility.

3. Strains to neck and shoulders. This has been in the past the main deterrent to testing human volunteers beyond 17.5 mph (28.2 kph). With appropriate instruction of the volunteer as to how to tense his muscles prior to impact, how to lean into the shoulder restraint and how to brace himself, this can be and has been minimized in the tests at Philadelphia. In spite of these measures you will feel some neck and shoulder discomfort beyond 15 - 17.5 mph (24.2 - 28.2 kph).

A physician will be in constant attendance at these tests. He will have resuscitative equipment on hand to include a portable resuscitator with oxygen, tourniquets, splints and those other tools needed should serious injury occur. In addition a litter and ambulance are immediately available for transporting an injured volunteer to the nearest hospital (7 minutes from SwRI) should this be needed.

After each test you participate in, you will be interviewed by the team physician as to your reactions to the test and will be examined by him, to be sure your clinical condition remains normal. In addition you will have an opportunity to view the films of one of the rides so that you can see the response of that subject to the impact. This will enable you to be better prepared for your next ride should you decide to continue in the program.

You will be permitted to withdraw from his program at any time you decide to do so without prejudice.

I, ____

residing at ____

____

hereby acknowledge and certify to the following:

1. That I hereby volunteer and consent to participate as a human test subject in an experiment designed to evaluate the effectiveness of a driver "Inflataband" seat belt restraint system by riding in a test "buck" on the SwRI Crash Impact Facility Sled at a simulated barrier crash impact speed not to exceed a 30 mph (48.3 kph) velocity change,

2. That I have been given, in my opinion, an adequate explanation of the nature, duration and purpose of the experiment, the means by which the experiment will be conducted and any possible inconveniences, hazards, discomforts, risks, and adverse effects on my health which could result from my participation therein;

3. That I understand my questions concerning procedures which affect me will be answered fully and promptly;

4. That I understand that I have the right to withdraw my consent and to discontinue participation in this experiment at any time without prejudice regardless of the status of the experiment and regardless of the effect of such withdrawal on the objectives and results which the experiment is designed to achieve; and I also understand that my participation in the experiment may be terminated at any time by the investigator in charge of the project or the physician supervising the project regardless of my wishes in the matter;

5. That I hereby understand and agree that I will be subjected to an interval type of physical examination and will inform the physician supervising the experiment, or the investigator in charge, of any change in my medical history, which information will include any medications I have taken and any medical or dental care or treatment I have received since my last physical examination performed at SwRI. I will also inform the physician of any changes in health and/or medical condition which may occur during the time I am a participant in these tests;

6. That I attained the age of ______ years on my last birthday which was ______________, and that I am executing this Volunteer's Informed Consent as my free act and deed.

Executed this ____________ day of ________________, 1975.

Executed in my presence and
in the presence of each other

____
Signature of volunteer

____
George C. Lawrason
Director, Automotive Research
Division

____

____
H. Haskell Ziperman, M.D.
Director, Department of Bioengineering

APPENDIX C

Mathematical Expressions Utilized

Mathematical Expressions Utilized

The digital computer program calculated the following quantities from the digitized data:

1. Sled Velocity Change
2. Resultant Head Acceleration
3. Resultant Chest Acceleration
4. Head Severity Index
5. Chest Severity Index
6. Head Injury Criterion
7. Resultant Toepan Load and Correction
8. Head Angular Velocity and Acceleration

The relationships used to compute the above quantities are listed below:

Item 1: Sled Velocity Change

$$\Delta v = \int_{t_o}^{t_f} a_s \, dt$$

where

$a \triangleq$ sled longitudinal acceleration, ft/sec^2

$t_o \triangleq$ time zero or event initiation, sec

$t_f \triangleq$ event termination, sec

or

$$t_f \triangleq t_o + \Delta t$$

where

$\Delta t \triangleq$ arbitrary time interval (nominally 250 msec)

Items 2 and 3: External Head or Chest Resultant Acceleration (Magnitude)

$$a = \sqrt{(a_x)^2 + (a_y)^2 + (a_z)^2}$$

where

$a_x \triangleq$ acceleration in the x direction as measured by the accelerometer at its point of attachment, g's

$a_y \triangleq$ acceleration in the y direction as measured by the accelerometer at its point of attachment, g's

$a_z \triangleq$ acceleration in the z direction as measured by the accelerometer at its point of attachment, g's

Items 4 and 5: Head or Chest Severity Index

$$SI = \int_{t_o}^{t_f} a^{2.5}\, dt$$

where

$a \triangleq$ external resultant acceleration for the head or chest, g's

$t_o \triangleq$ event initiation, sec

$t_f \triangleq$ event termination, sec

Item 6: Head Injury Criterion

$$HIC = t_2 - t_1 \left[\frac{\int_{t_1}^{t_2} a\, dt}{t_2 - t_1} \right]^{2.5}$$

where

$a \triangleq$ external resultant head acceleration, g's

$t_1, t_2 =$ any two points in time during the test event such that $t_2 > t_1$, and HIC is the maximum value.

Item 7: Resultant Toepan Load and Correction

$$F = \sqrt{(F_x)^2 + (F_y)^2}$$

where

$F_x \triangleq$ corrected load appied in the x direction as measured by left or right load cell, lbf

$F_y \triangleq$ corrected load appied in the y direction as measured by left or right load cell, lbf

Correction term:

The correction term for the left and right "y" component is given by the expression

$$F_y = k_1 a_s$$

where

$k_1 \triangleq 10.82$ lbf/g (constant due to plate angular orientation and (mass)

$a_s \triangleq$ sled acceleration, g's

The correction term for the left and right "x" component is given by the expression

$$F_x = k_2 a_s$$

where

$k_2 \triangleq 6.25$ lbf/g (constant due to plate angular orientation and mass)

$a_s \triangleq$ sled acceleration, g's

Item 8: Head Angular Velocity and Acceleration.

As originally conceived, the accelerations measured with the head pack cluster could be used to compute head angular velocity and acceleration. These values, with an estimate of spatial location of the accelerometers with respect to the head center of gravity, would then be used to correct the head resultant acceleration as measured externally to the resultant acceleration of the head center of gravity. The equations utilized are presented as follows:

$$\dot{w}_z = \frac{a_{2y} - a_{1y}}{x} - w_x w_y$$

$$\dot{w}_y = w_x w_z - \frac{a_{2z} - a_{1z}}{x}$$

$$\dot{w}_x = w_y w_z - \frac{a_{3y} - a_{1y}}{z}$$

where

$\dot{w}_j$ = angular acceleration, about j axis, sec^{-2}

w_j = angular velocity, about j axis, sec^{-1}

a_{ij} = component (j) of acceleration measured at the indicated location (i), $ft\text{-}sec^{-2}$

x, z = separation distance along the appropriate axis between indicated accelerometer locations, ft.

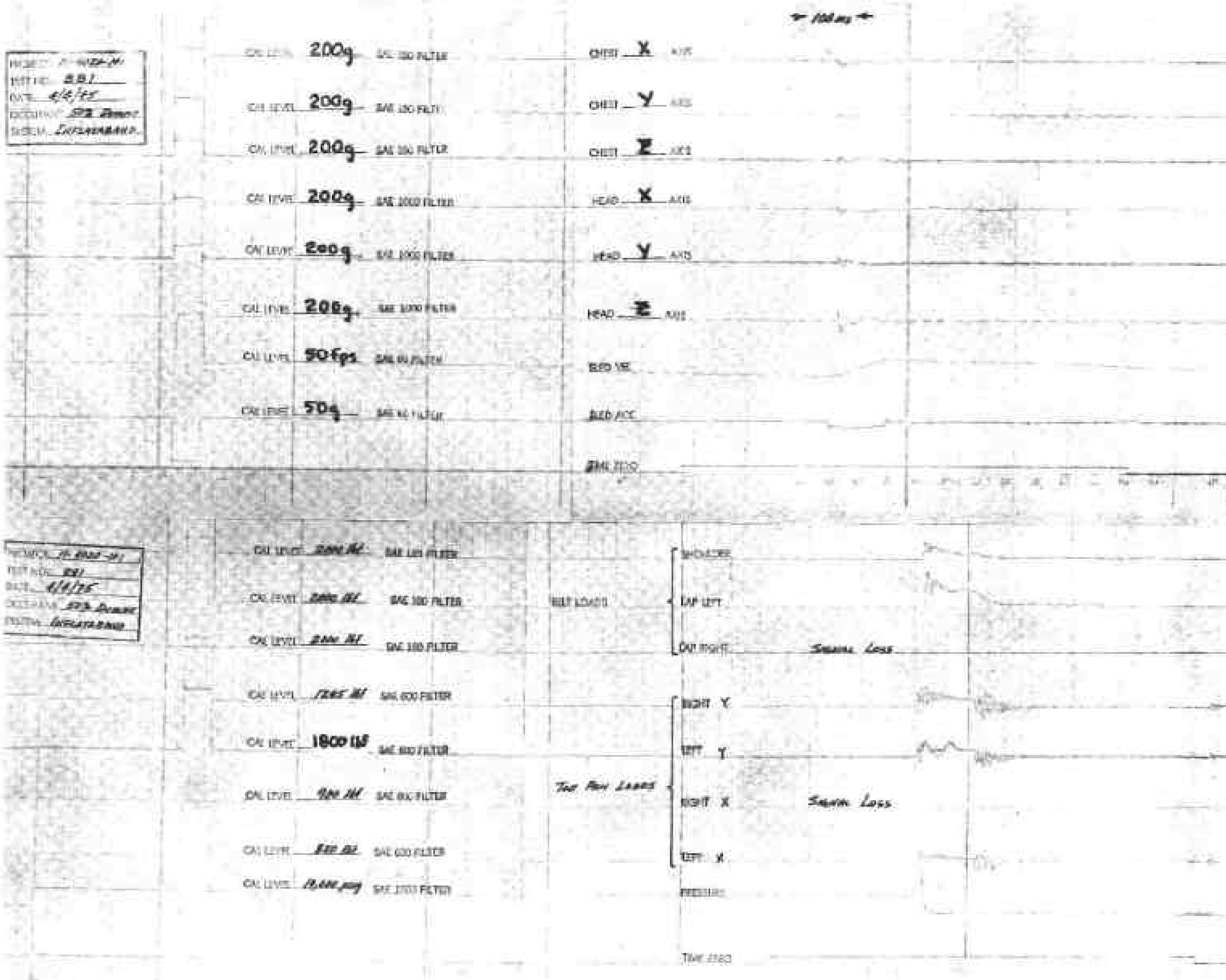
Since the determination of the angular components requires the solution of three simultaneous differential equations for which an exact solution does not exist, numerical methods were utilized. Because of the sensitivity of the technique to the accuracy of the measured data, the results were not utilized to correct the external head resultant acceleration. Error analysis has indicated that in order to obtain reliable angular acceleration results, the accuracy of the measured data must be approximately 0.1% of the peak linear acceleration.

APPENDIX D

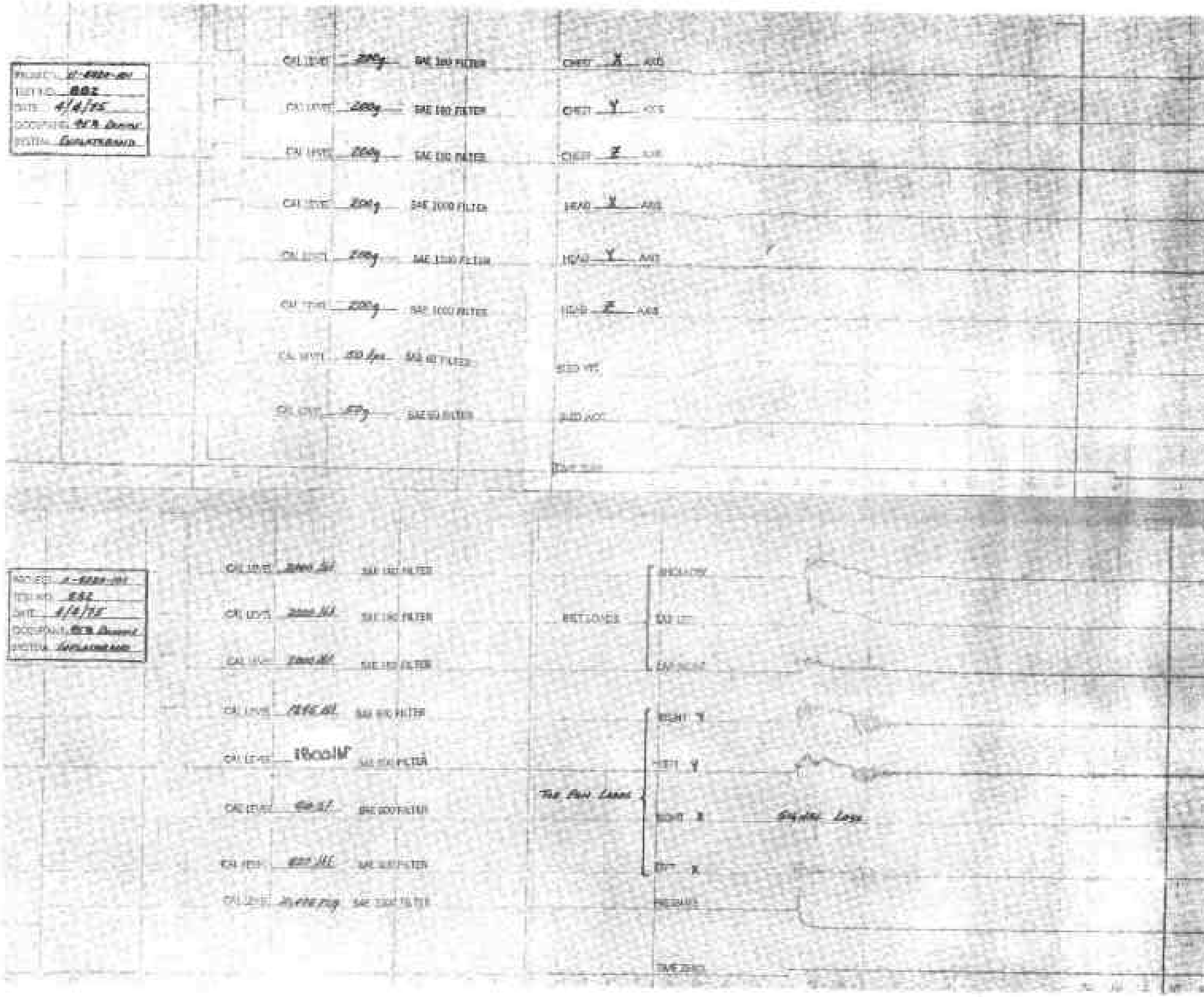
Production Test Analog Signal Summaries

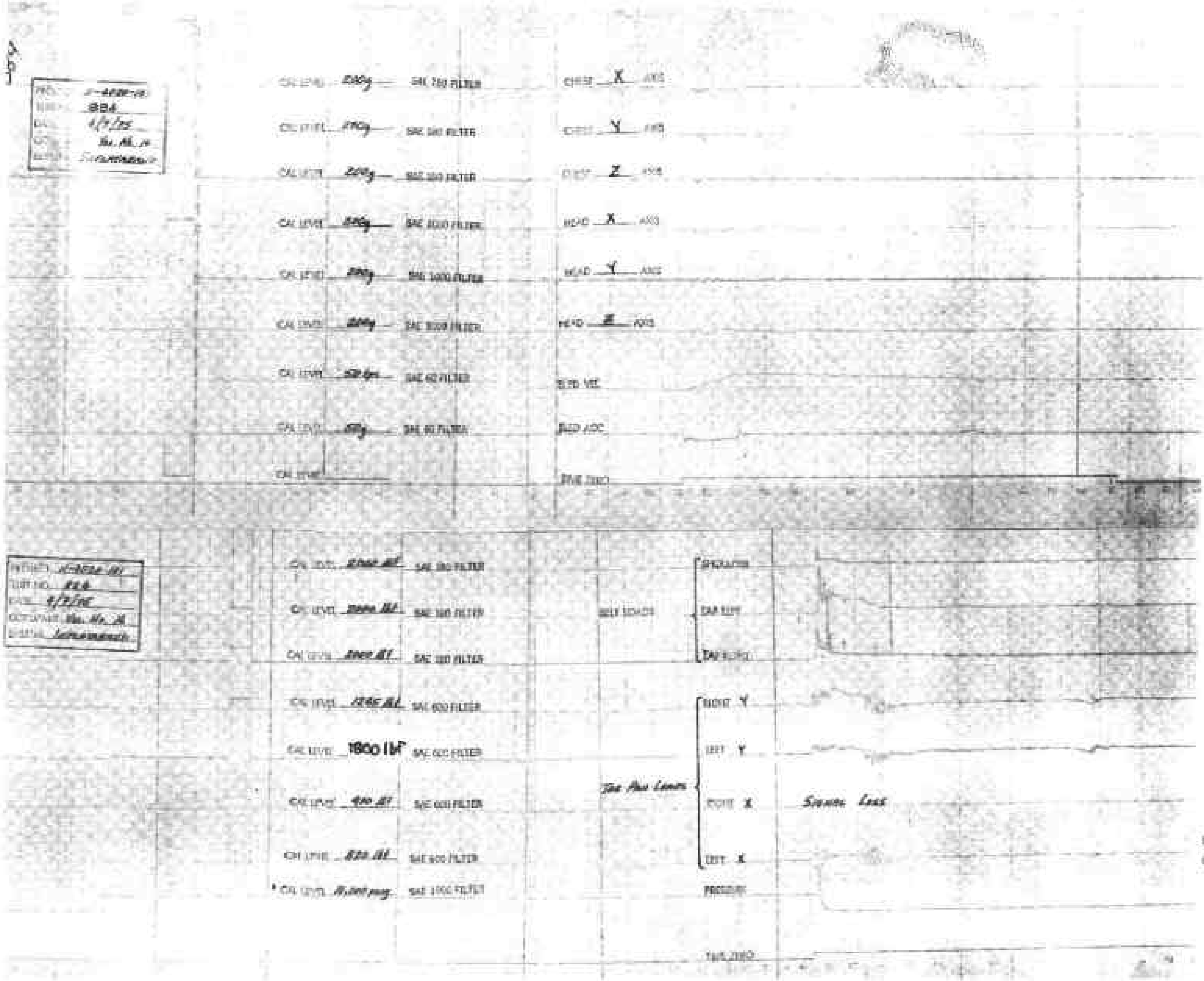
Production Test Analog Signal Summaries

The time scale for the analog summaries presented is 100 msec per division during the event. The initiation of the event is indicated by the step change on the Time Zero Channel.


100 ms
CAL LEVEL 200g SAE 180 FILTER
CHEST X AXIS
CAL LEVEL 200g
CHEST Y AXIS
CAL LEVEL 200g SAE 180 FILTER
CHEST Z AXIS
CAL LEVEL 200g SAE 1000 FILTER
HEAD X AXIS
CAL LEVEL 200g SAE 1000 FILTER
HEAD Y AXIS
CAL LEVEL 200g SAE 1000 FILTER
HEAD Z AXIS
CAL LEVEL 50 fps
SLED VEL
CAL LEVEL 50g
SLED ACC
CAL LEVEL SAE 180 FILTER
SHOULDER
CAL LEVEL SAE 180 FILTER
BELT LOADS
LAP LEFT
CAL LEVEL SAE 180 FILTER
LAP RIGHT
Signal Loss
CAL LEVEL SAE 600 FILTER
RIGHT Y
CAL LEVEL 1800 LBS SAE 600 FILTER
LEFT Y
Tie Pin Loads
CAL LEVEL SAE 600 FILTER
RIGHT X
Signal Loss
CAL LEVEL SAE 600 FILTER
LEFT X
CAL LEVEL SAE 2000 FILTER
PRESSURE
TIME ZERO

D-3


PROJECT: U-8820-101
TEST NO. 802
DATE 4/4/75
CAL LEVEL 200g SAE 180 FILTER
CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
CAL LEVEL 200g SAE 1000 FILTER
SAE 60 FILTER
SLED VEL
SLED ACC
TIME ZERO
BELT LOADS
SHOULDER
LAP LEFT
LAP RIGHT
CAL LEVEL 1800 lbf
SAE 180 FILTER
The Pan Loads
RIGHT Y
LEFT Y
RIGHT X
LEFT X
Signal Loss
PRESSURE
SAE 1000 FILTER



CAL LEVEL 250g SAE 180 FILTER
CHEST X AXIS
CAL LEVEL 250g SAE 180 FILTER
CHEST Y AXIS
CAL LEVEL 250g SAE 180 FILTER
CHEST Z AXIS
CAL LEVEL 250g SAE 1000 FILTER
HEAD X AXIS
CAL LEVEL 250g SAE 1000 FILTER
HEAD Y AXIS
CAL LEVEL 250g SAE 1000 FILTER
HEAD Z AXIS
SAE 60 FILTER
SLED VEL
SAE 60 FILTER
SLED ACC
CAL LEVEL
TIME ZERO
CAL LEVEL SAE 180 FILTER
CAL LEVEL SAE 180 FILTER
CAL LEVEL SAE 180 FILTER
BELT LOADS
SHOULDER
LAP LEFT
LAP RIGHT
CAL LEVEL SAE 600 FILTER
CAL LEVEL 1800 lbF SAE 600 FILTER
CAL LEVEL SAE 600 FILTER
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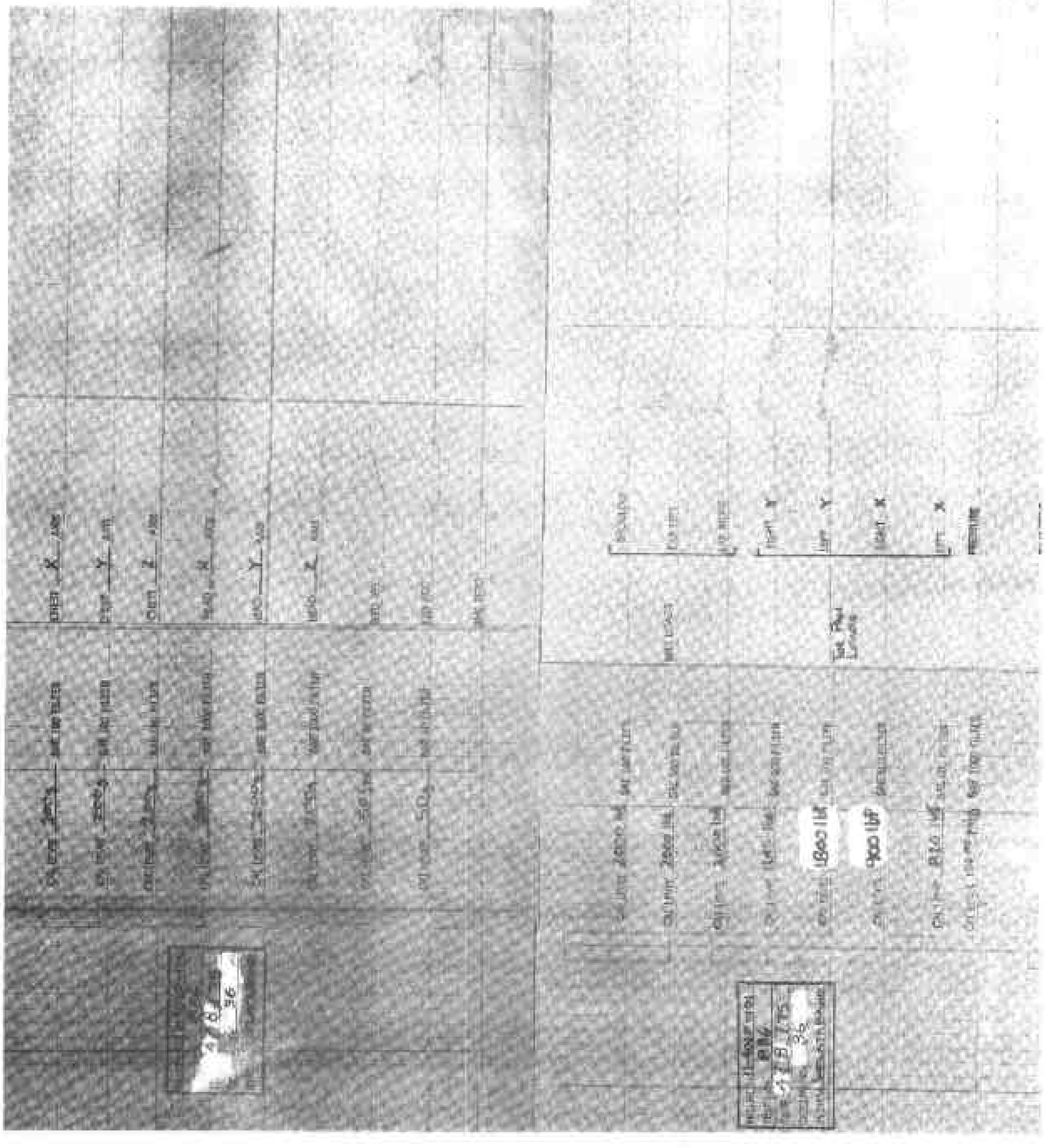
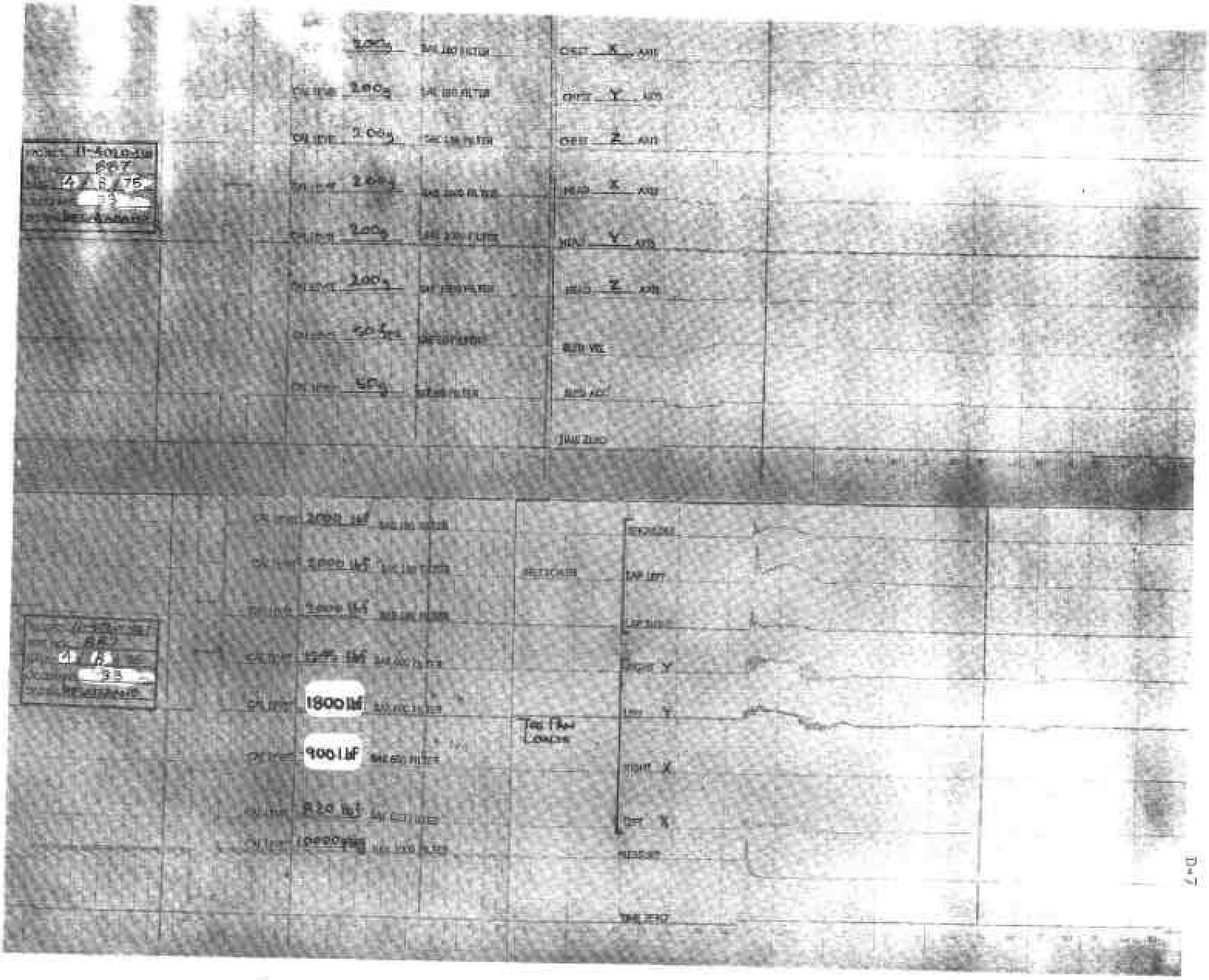
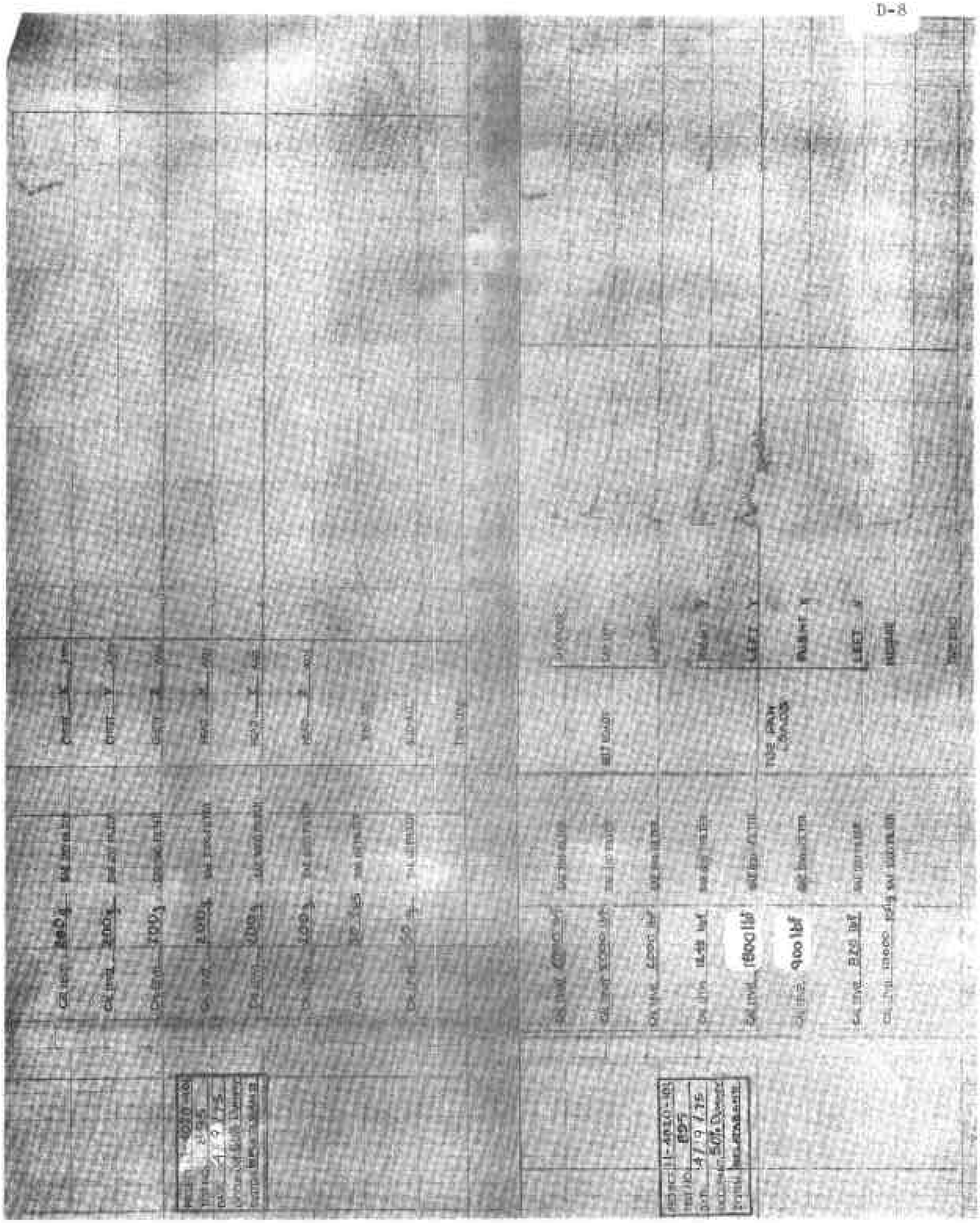
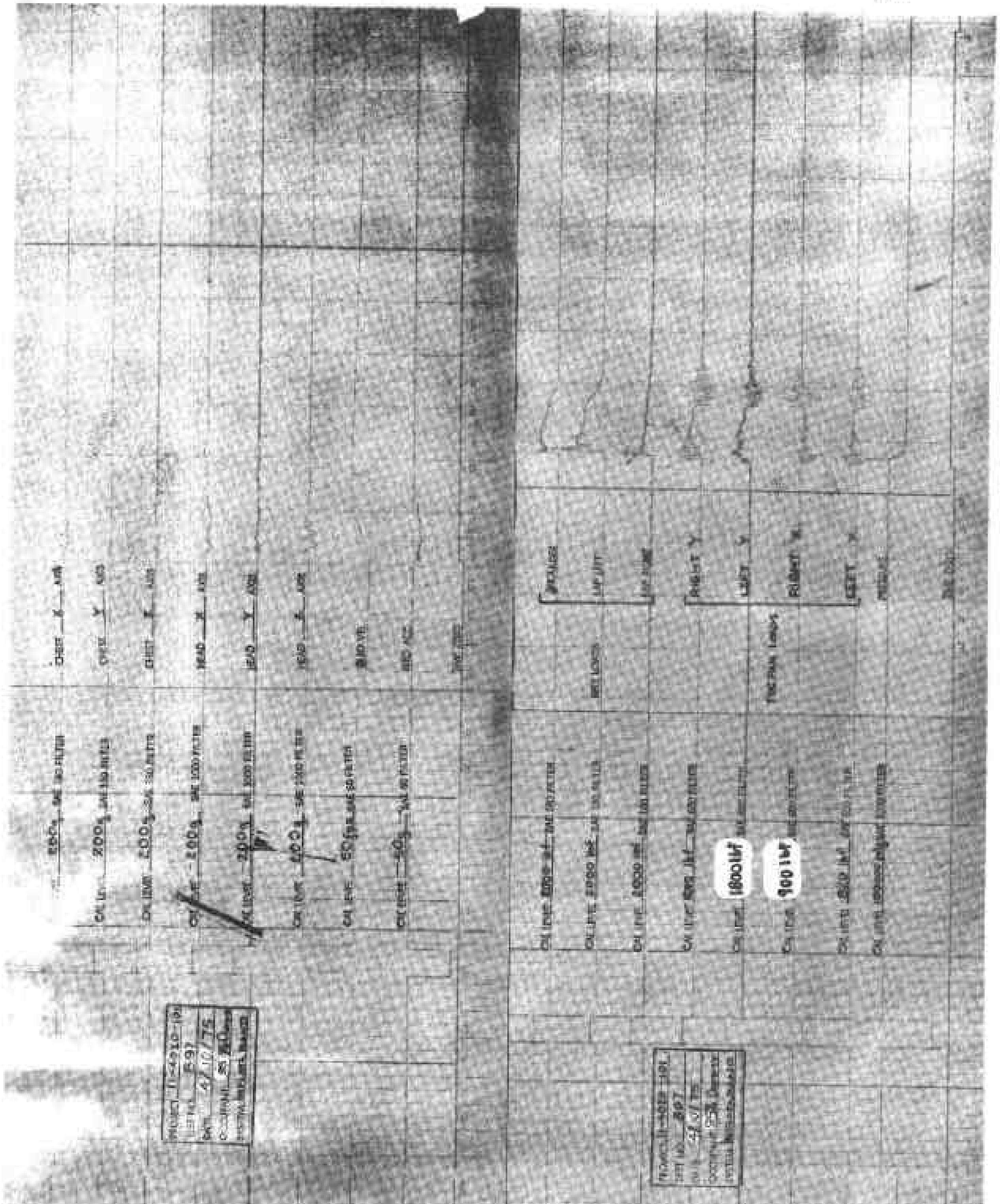
RIGHT X
LEFT X
Signal Lost
PRESSURE
TIME ZERO

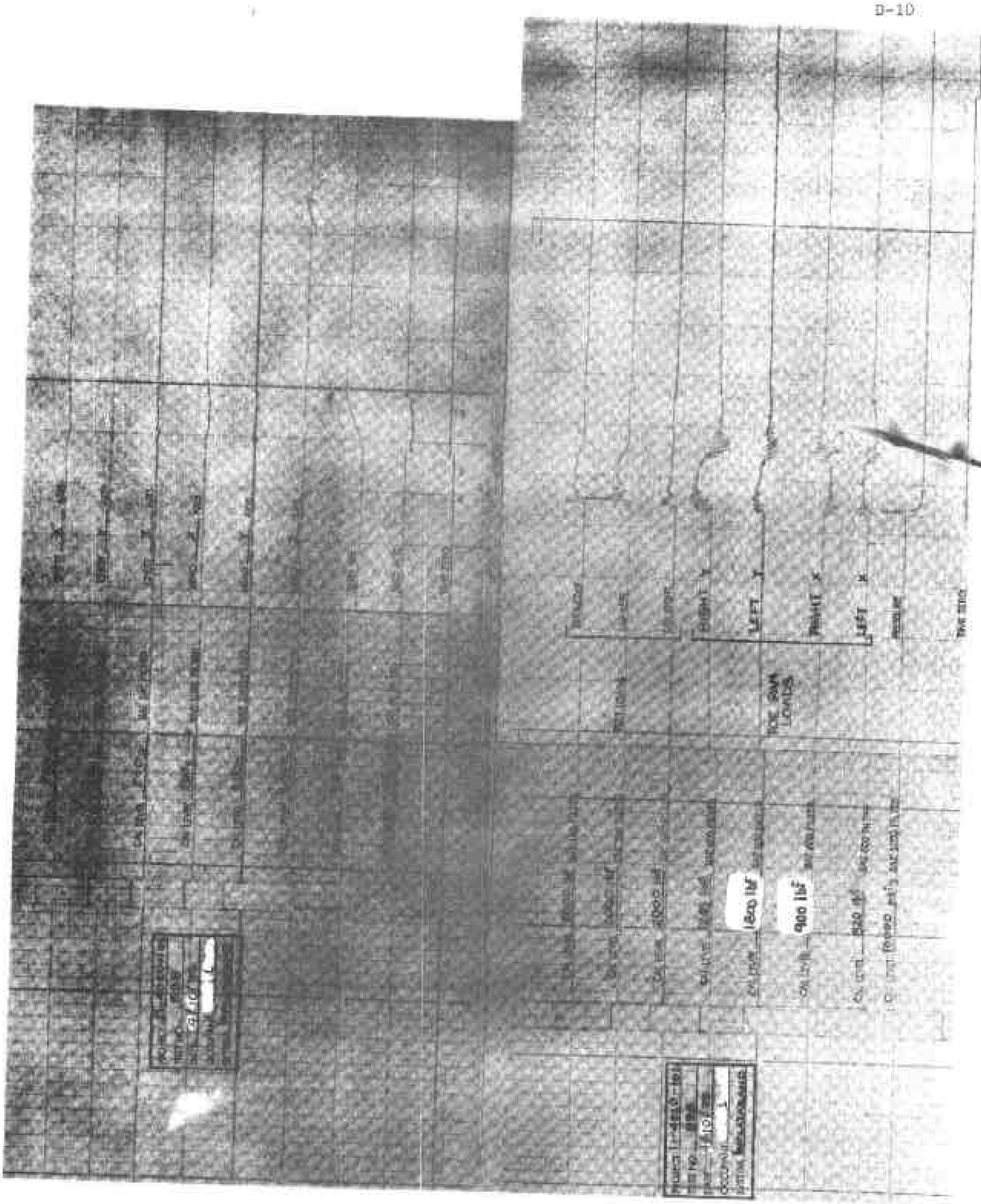


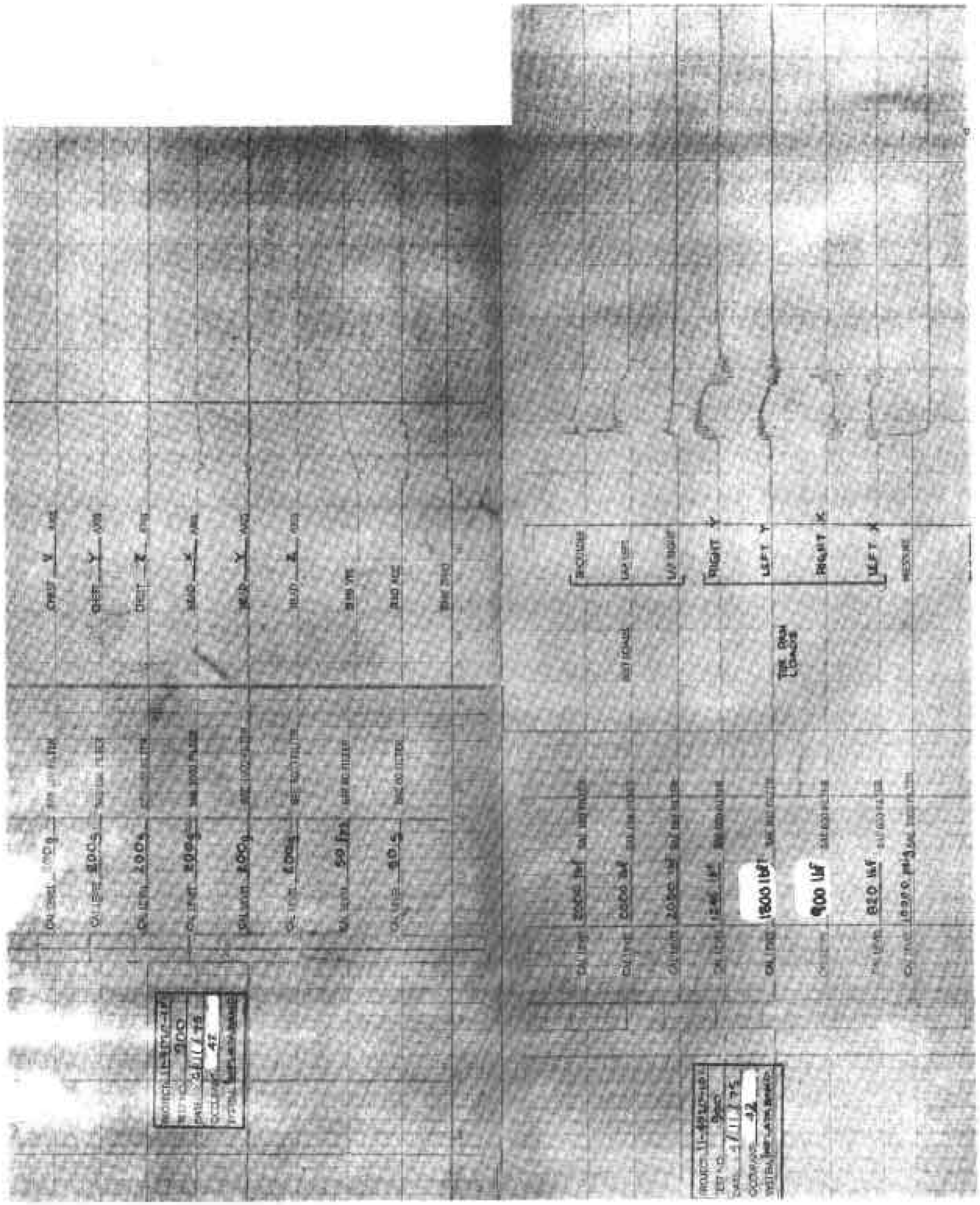


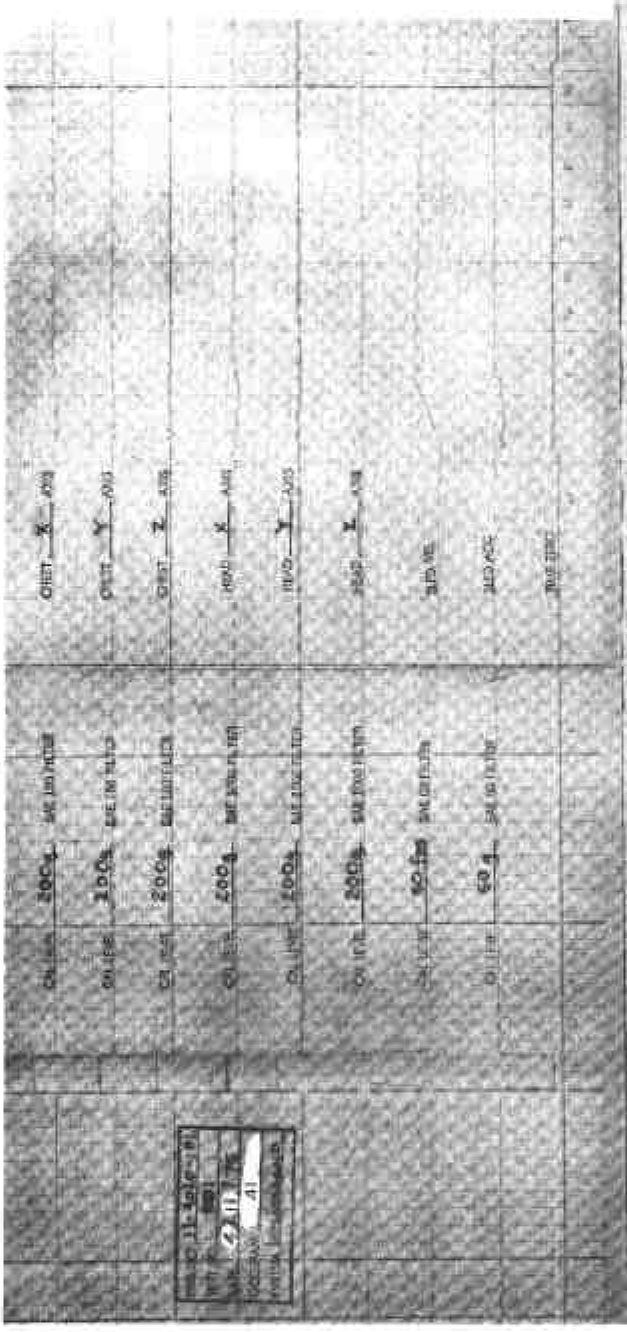
200g
200g
200g
200g
200g
200g
50g
X
Y
Z
X
Y
Z
1800 lbF
900 lbF
820 lbf

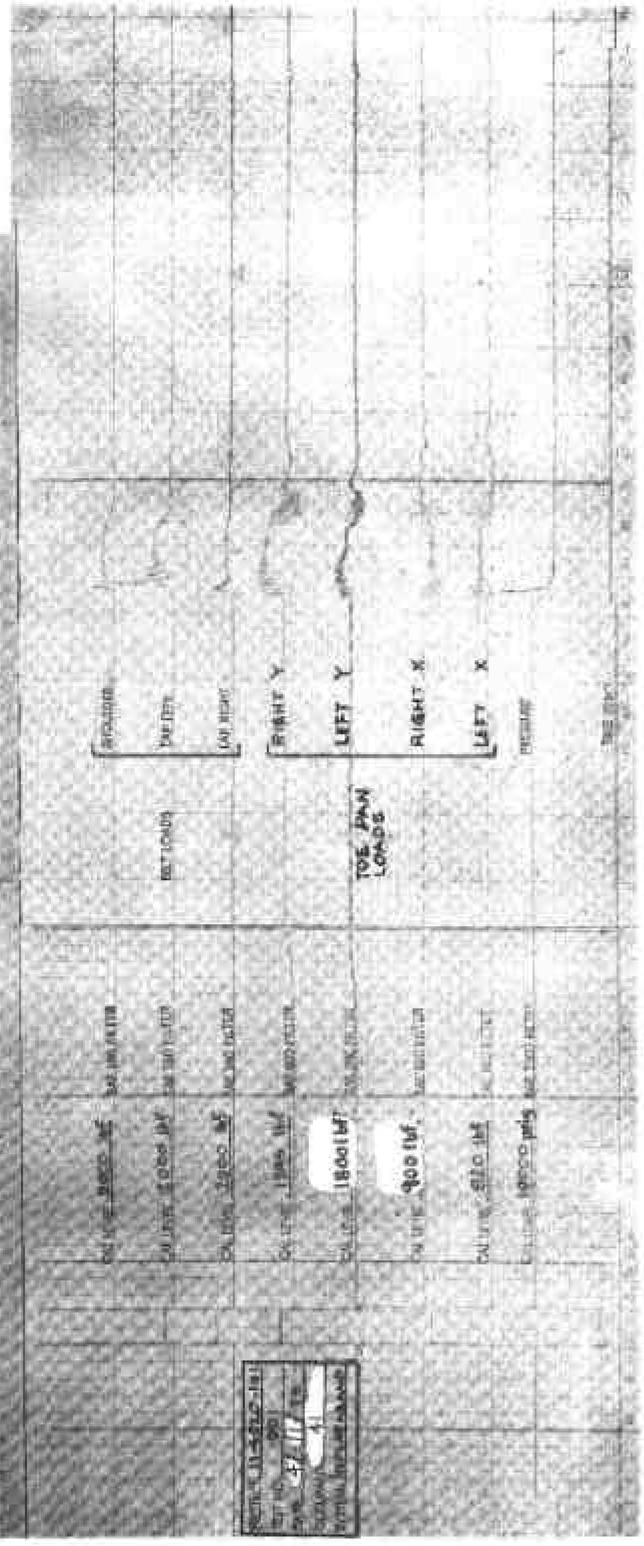

11-4020-101
895
4/9/75
50% Dummy
280 g
200 g
1800 lbf
900 lbf
TOE PAN LOADS
LEFT Y
RIGHT X
LEFT X

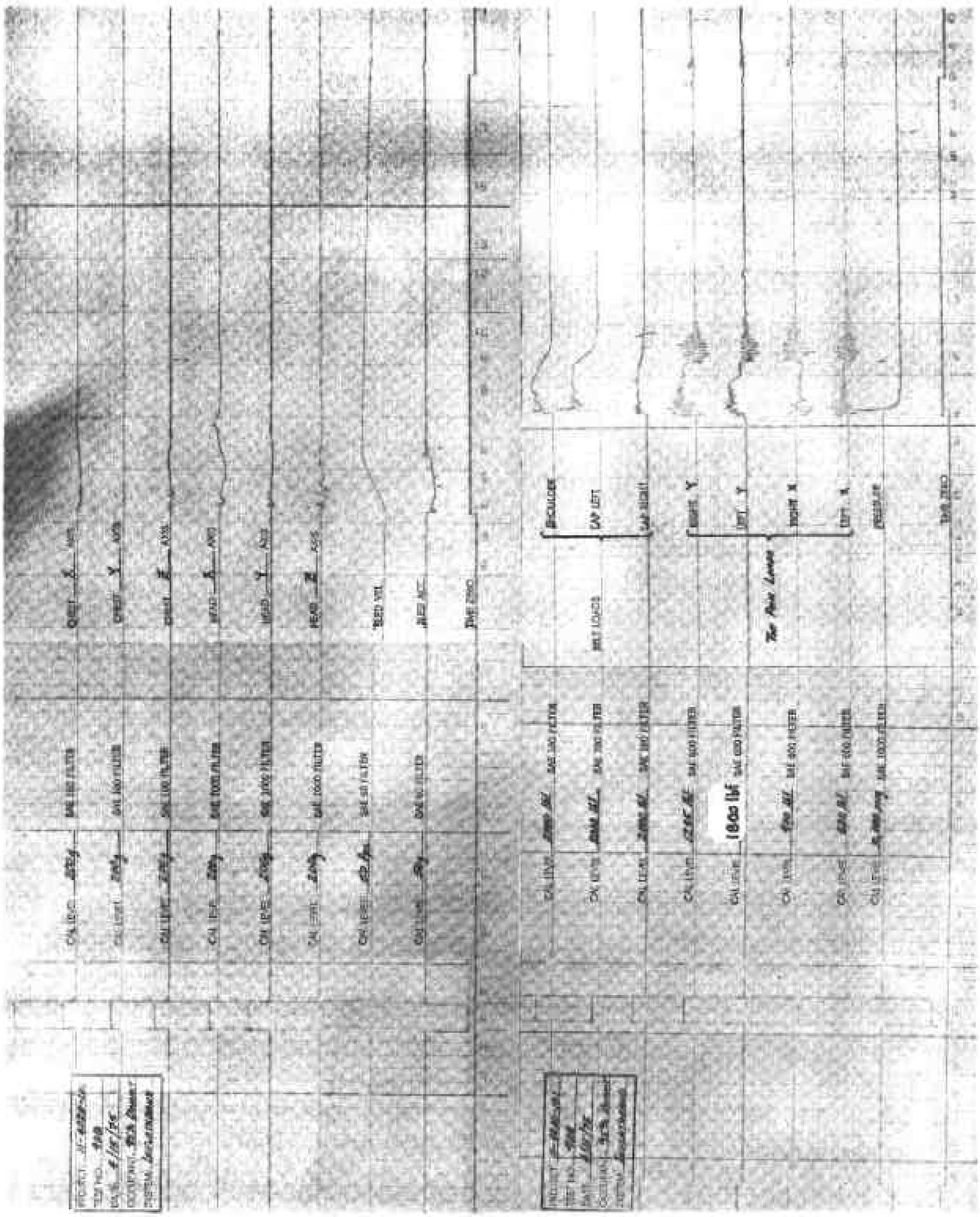


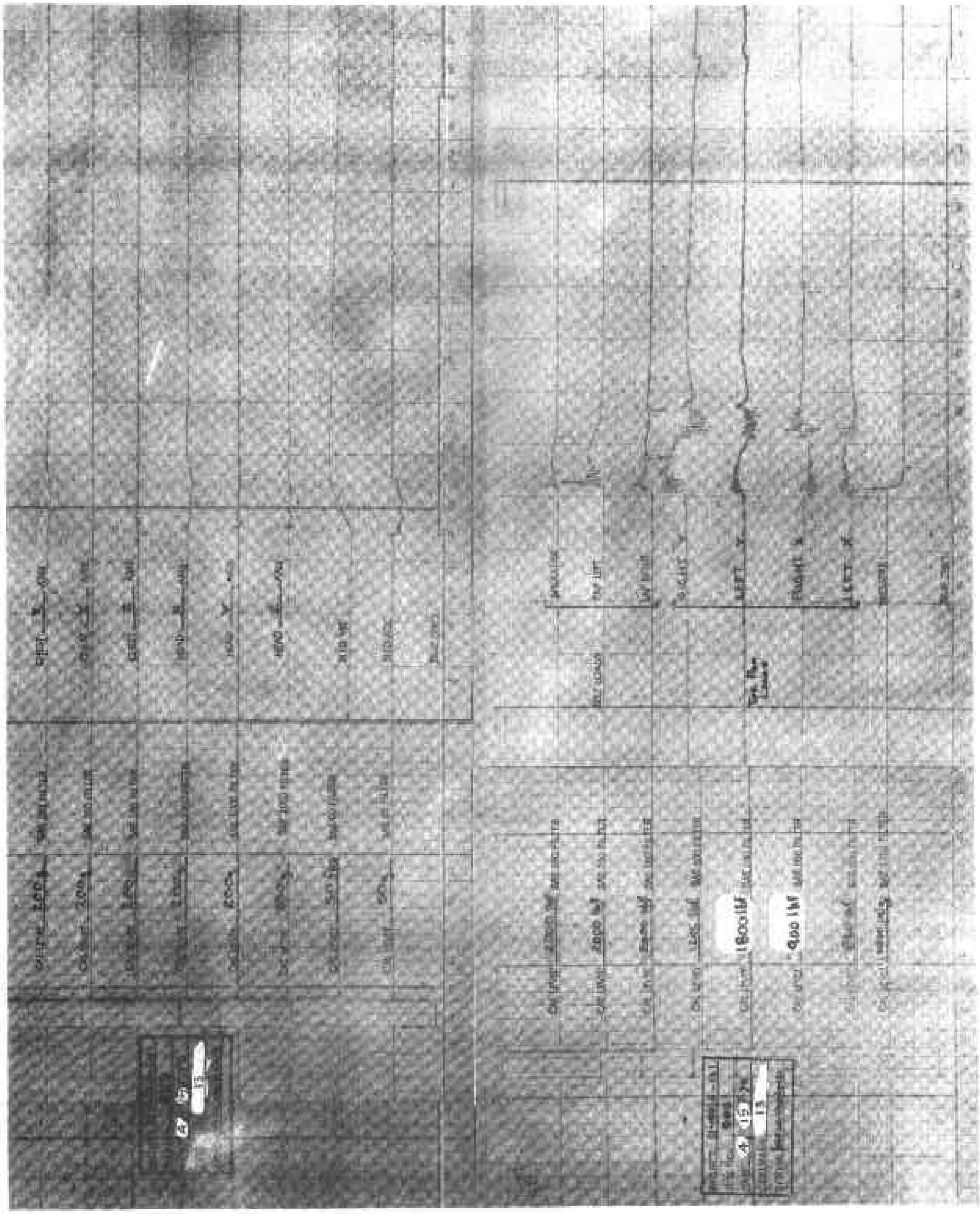

TOE PAN LOADS
RIGHT Y
LEFT Y
RIGHT X
LEFT X
1800 lbf
900 lbf

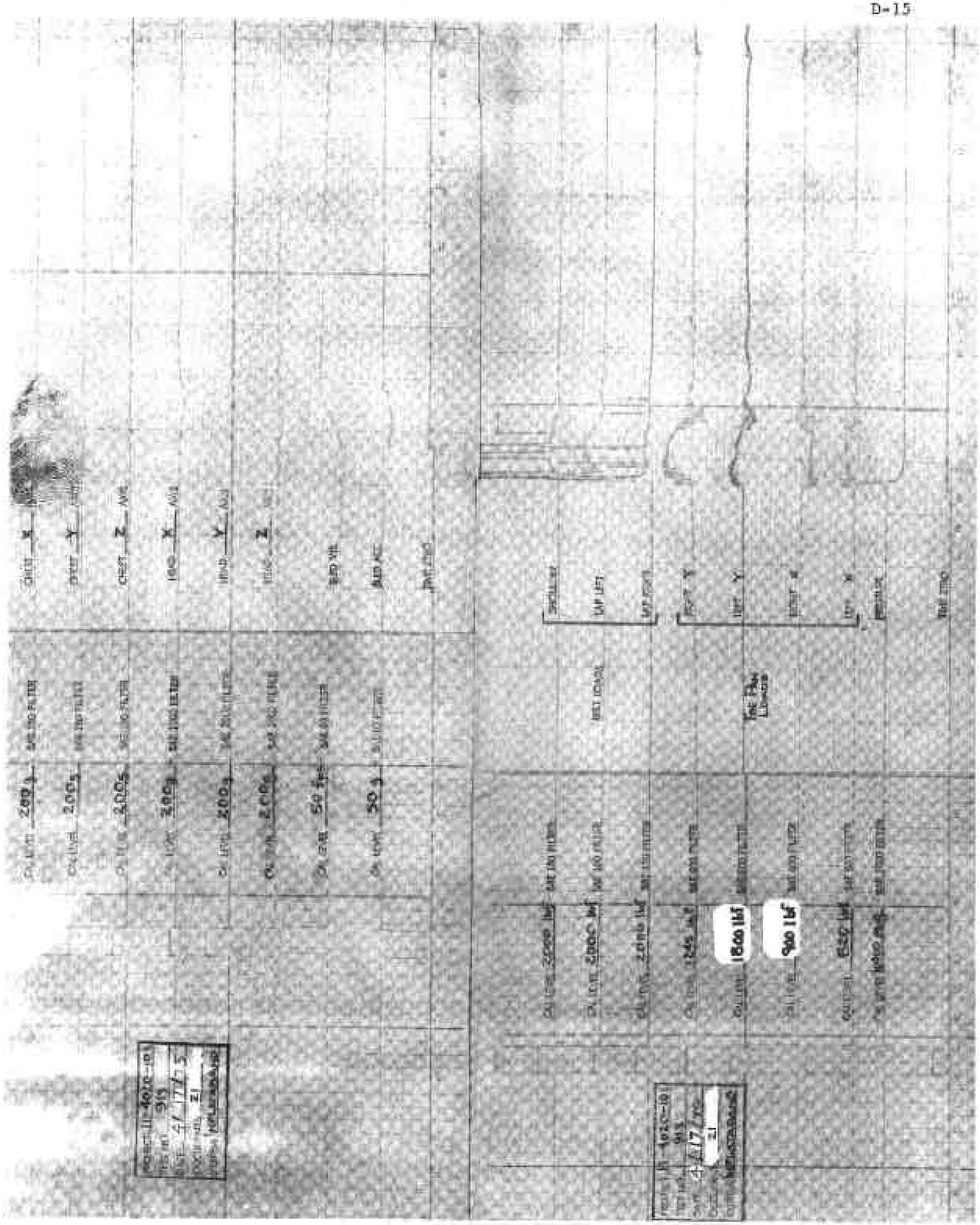


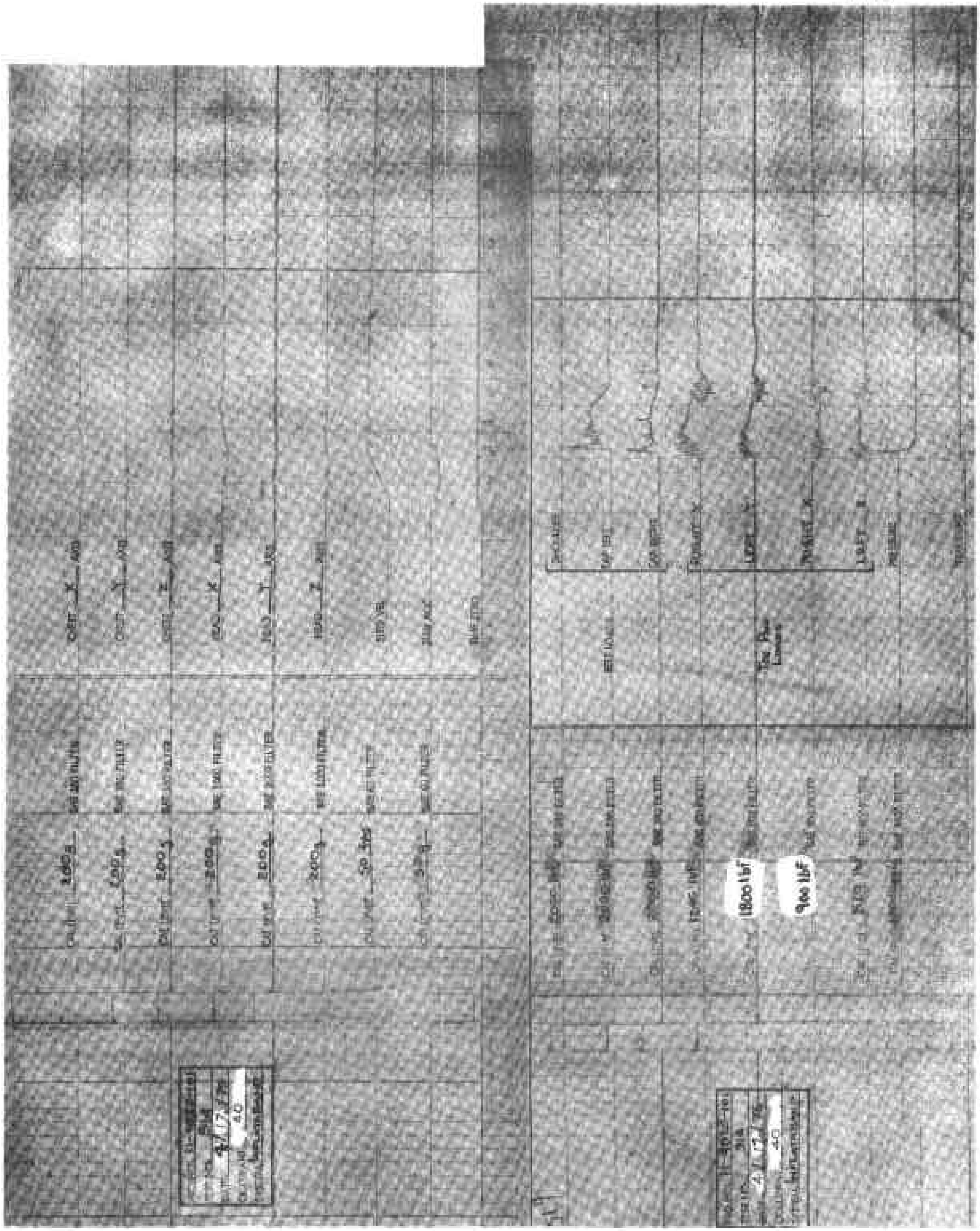


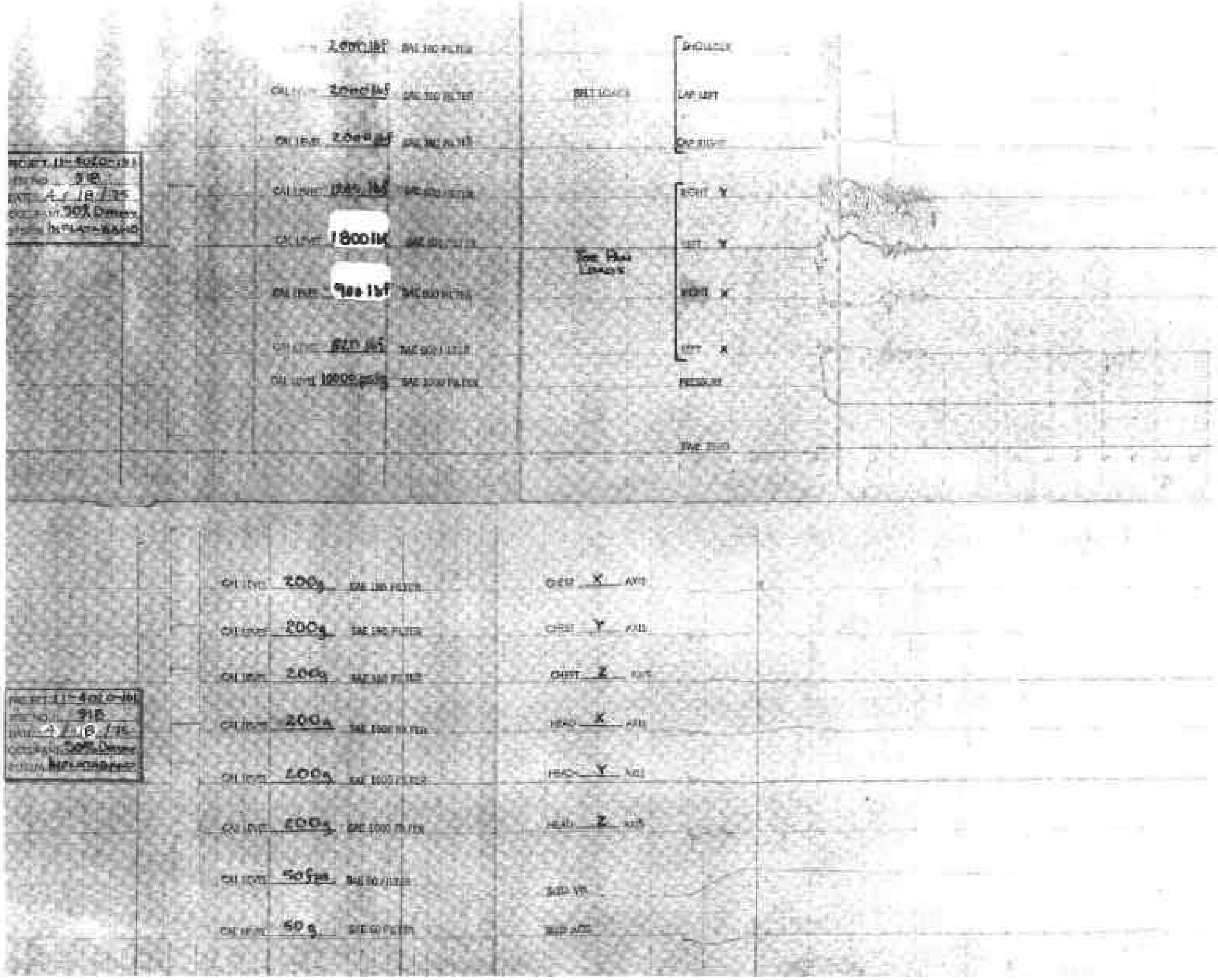

BELT LOADS
TOE PAN LOADS
RIGHT Y
LEFT Y
RIGHT X
LEFT X



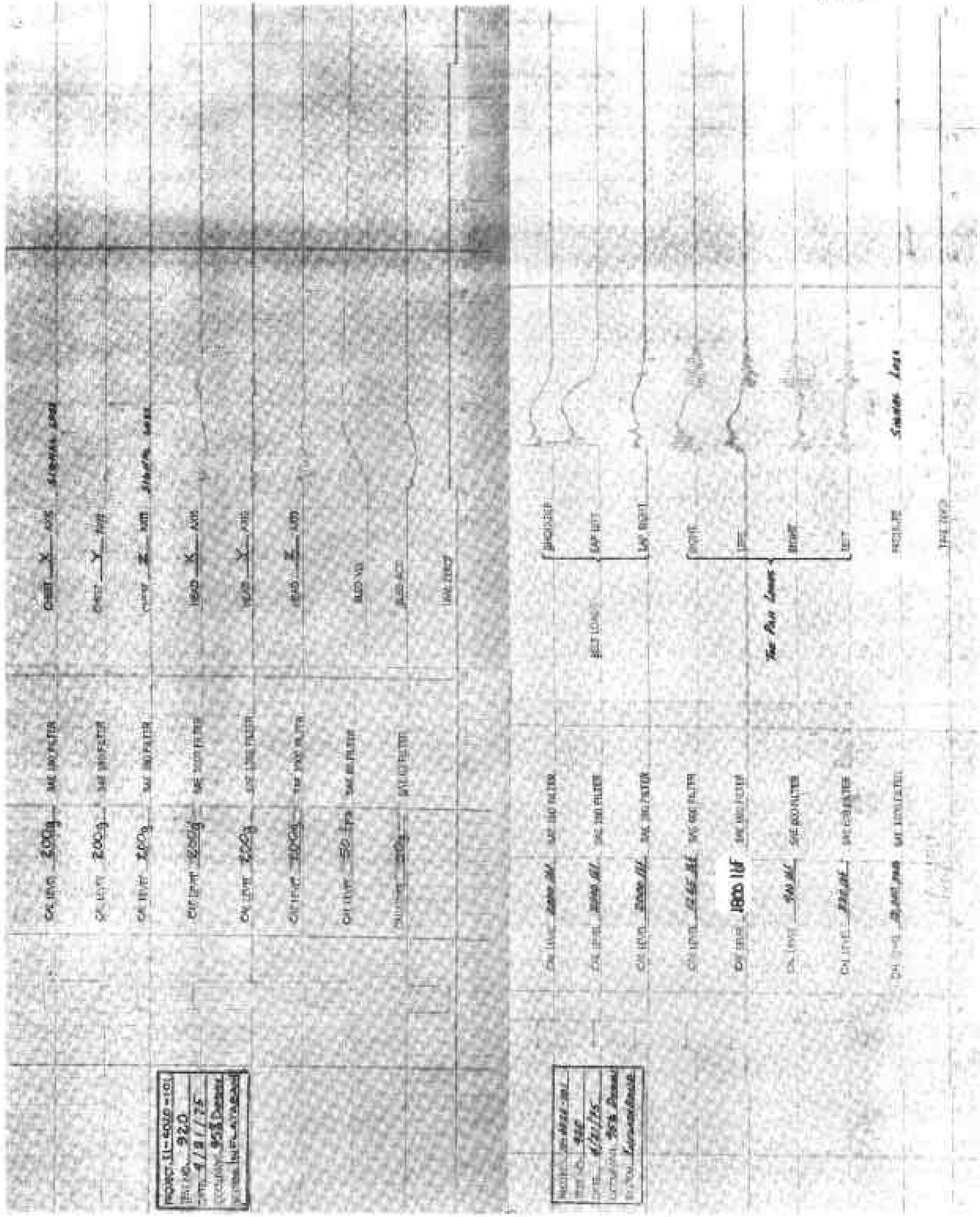


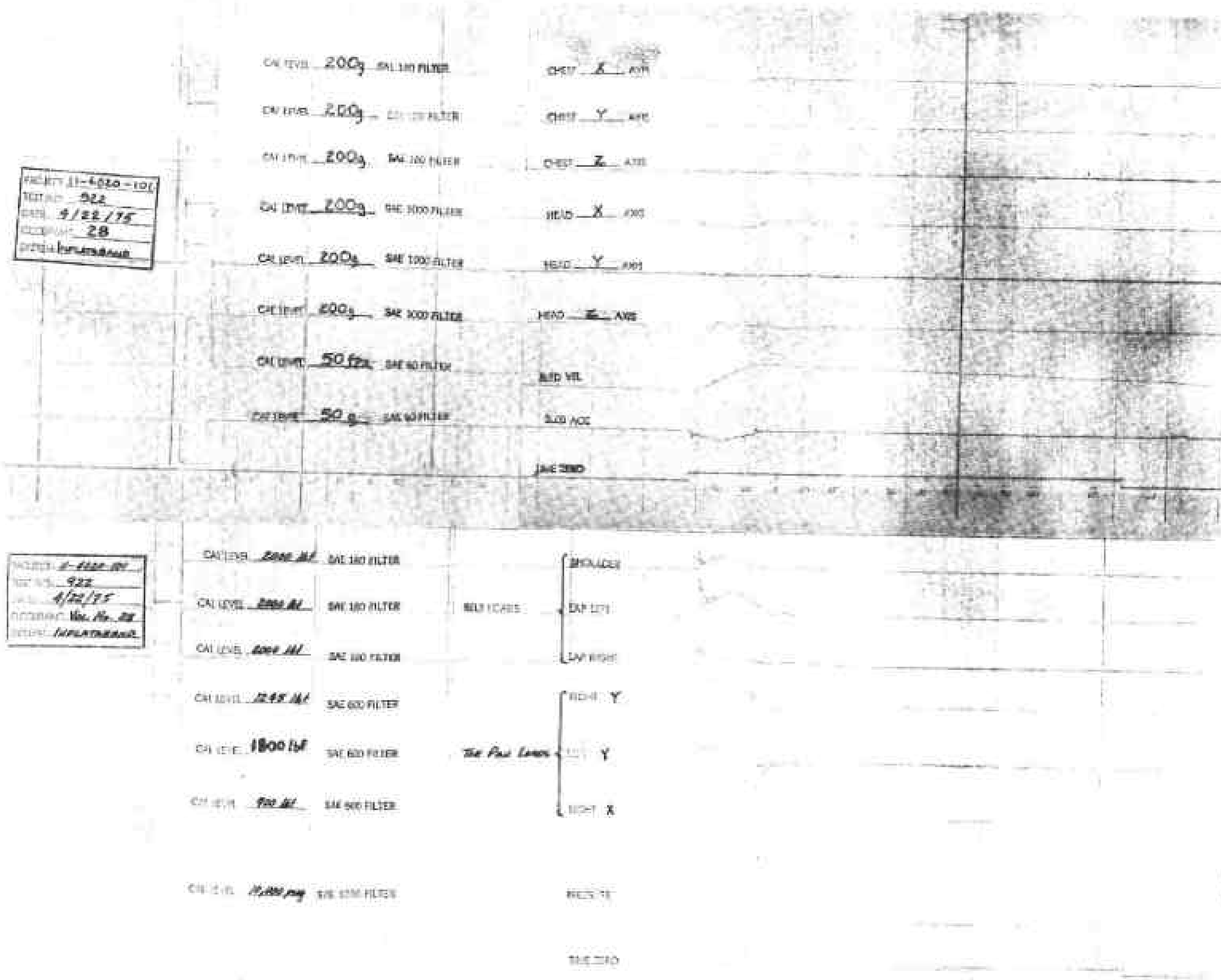


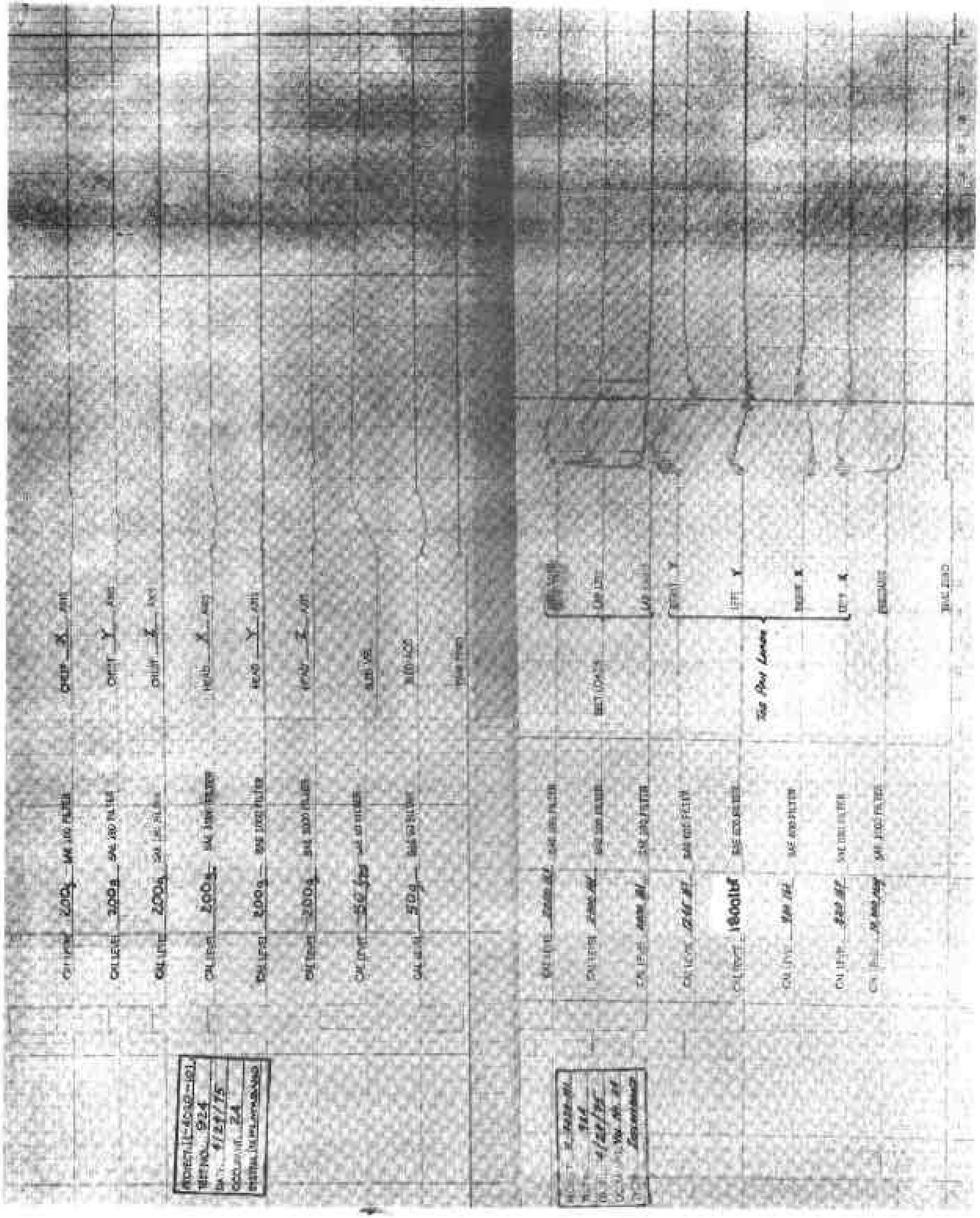




CAL LEVEL 2000 lbf
CAL LEVEL 1800 lbf
CAL LEVEL 900 lbf
CAL LEVEL 820 lbf
BELT LOADS
SHOULDER
LAP LEFT
LAP RIGHT
TOE PAN LOADS
RIGHT Y
LEFT Y
RIGHT X
LEFT X
PRESSURE
TIME ZERO
CAL LEVEL 200g
CAL LEVEL 50 fps
CAL LEVEL 50 g
CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
SLED VEL
SLED ACC
TEST NO. 918
DATE 4/18/75
50% Dummy

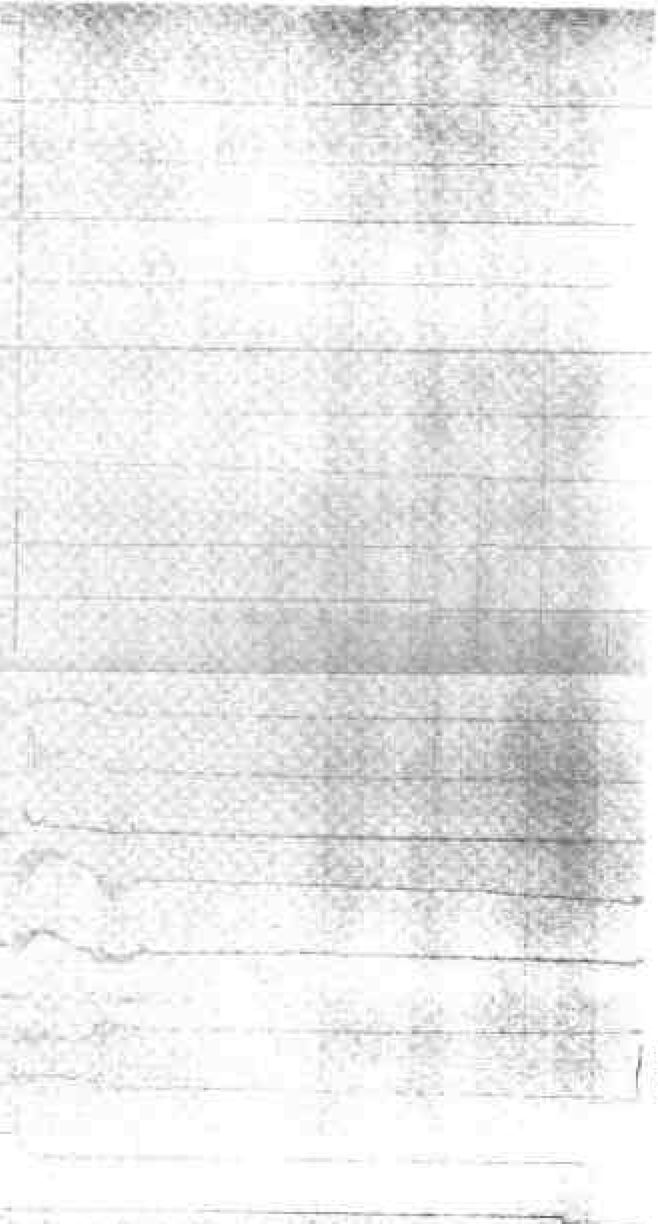



TEST NO. 922
DATE 4/22/75
OCCUPANT 28
CAL LEVEL 200g SAE 180 FILTER CHEST X AXIS
CAL LEVEL 200g CHEST Y AXIS
CAL LEVEL 200g SAE 180 FILTER CHEST Z AXIS
CAL LEVEL 200g SAE 1000 FILTER HEAD X AXIS
CAL LEVEL 200g SAE 1000 FILTER HEAD Y AXIS
CAL LEVEL 200g SAE 1000 FILTER HEAD Z AXIS
CAL LEVEL 50 fps SAE 60 FILTER SLED VEL
CAL LEVEL 50 g SAE 60 FILTER SLED ACC
TIME ZERO
TEST NO. 922
DATE 4/22/75
CAL LEVEL SAE 180 FILTER SHOULDER
CAL LEVEL SAE 180 FILTER BELT LOADS
CAL LEVEL SAE 180 FILTER
CAL LEVEL SAE 600 FILTER RIGHT Y
CAL LEVEL 1800 lbf SAE 600 FILTER Y
CAL LEVEL SAE 600 FILTER RIGHT X
CAL LEVEL SAE FILTER
TIME ZERO

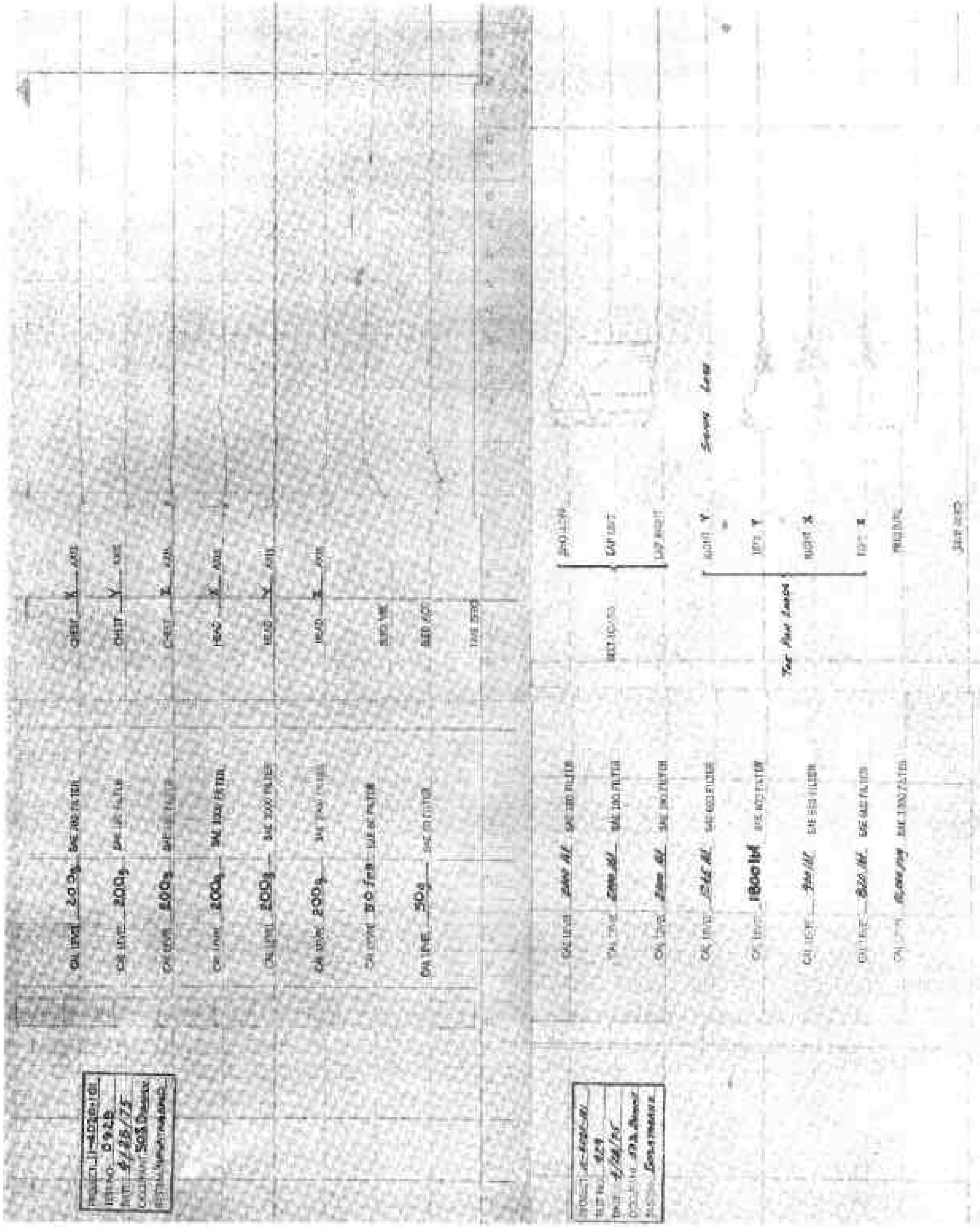

PROJECT 11-4040-101
TEST NO. 924
DATE 4/29/75
OCCUPANT 2A
CAL LEVEL 200g
CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
CAL LEVEL 50g
SLED VEL
SLED ACC
TIME ZERO
BELT LOADS
CAL LEVEL 1800 lbf
LEFT Y
RIGHT X
LEFT X
TIME ZERO

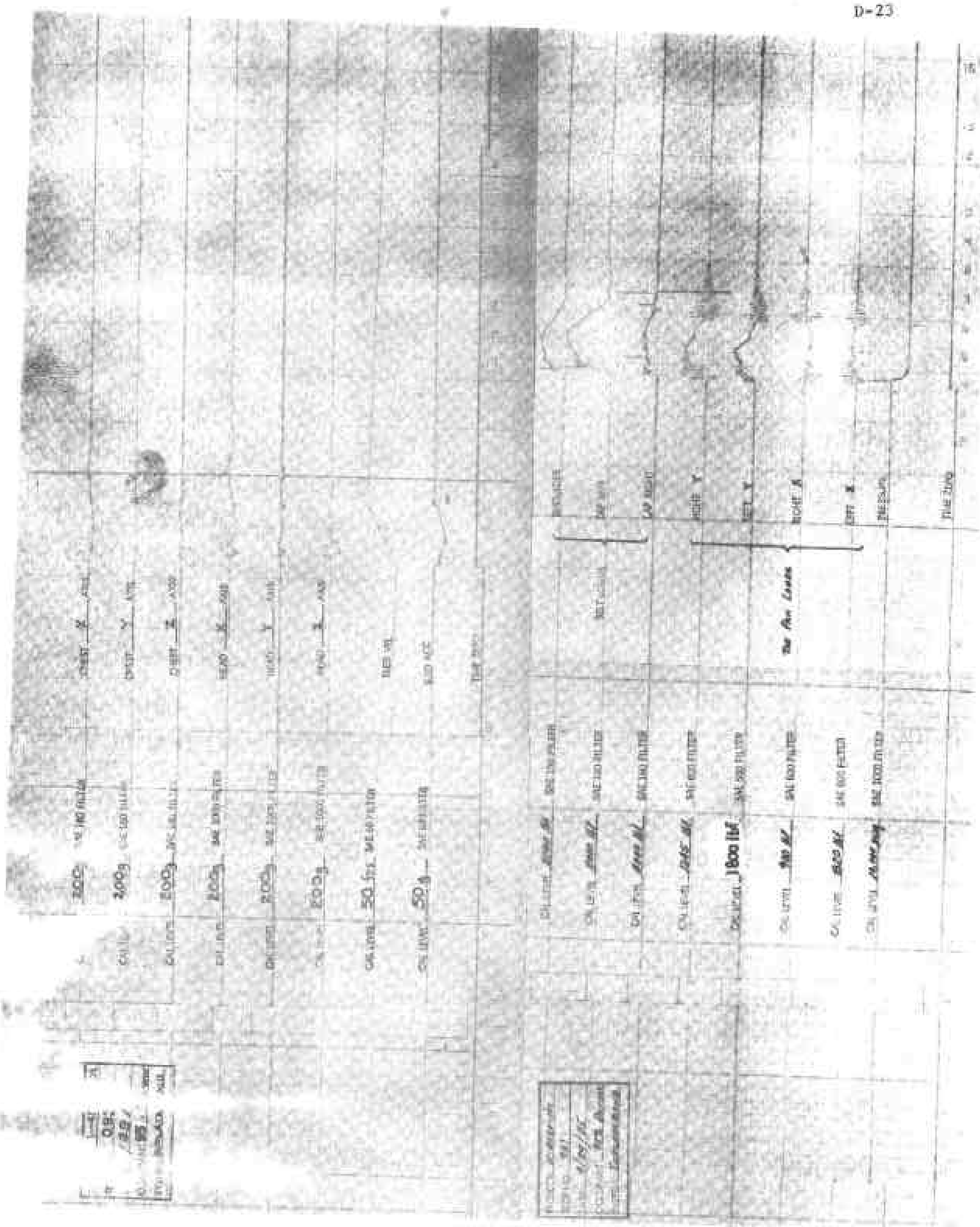
CAL LEVEL 200g — SAE 1000 FILTER — CHEST X ACC
CAL LEVEL 200g — CHEST Y ACC
CAL LEVEL 200g — SAE 1000 FILTER — CHEST Z ACC
CAL LEVEL 200g — SAE 1000 FILTER — HEAD X ACC
CAL LEVEL 200g — SAE 1000 FILTER — HEAD Y ACC
CAL LEVEL 200g — SAE 1000 FILTER — HEAD Z ACC
CAL LEVEL 50g — SAE 60 FILTER — SLED VEL
CAL LEVEL 50g — SAE 60 FILTER — SLED ACC
TIME ZERO

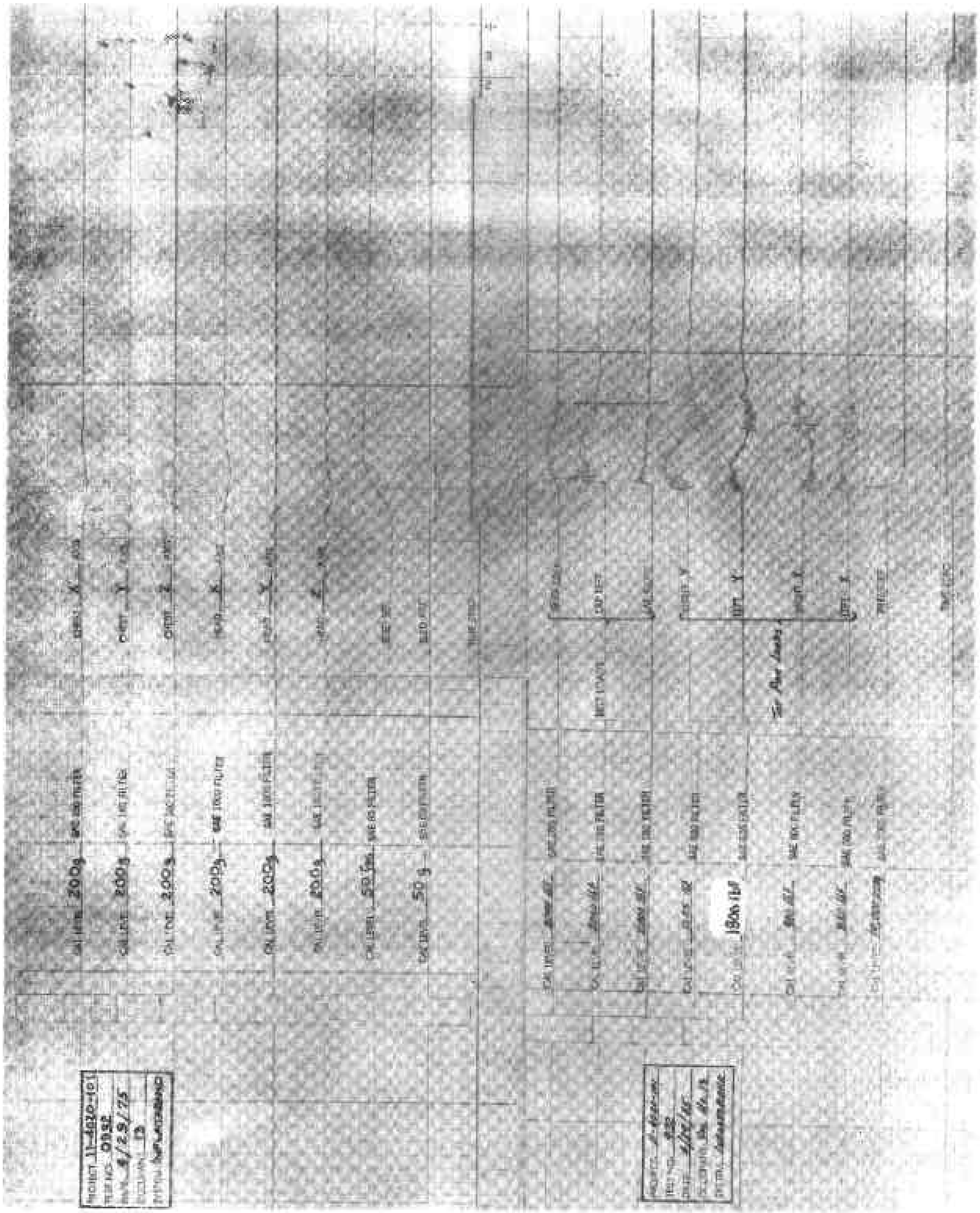
CAL LEVEL — SAE 100 FILTER — SHOULDER
CAL LEVEL — SAE 100 FILTER — BELT LOADS — LAP LEFT
CAL LEVEL — SAE 100 FILTER — LAP RIGHT
CAL LEVEL — SAE 600 FILTER — RIGHT Y
CAL LEVEL 1500 LLF — SAE 100 FILTER — LEFT Y
CAL LEVEL — SAE 600 FILTER — The Pad Loads — RIGHT X
CAL LEVEL — SAE 600 FILTER — LEFT X
CAL LEVEL — SAE 1000 FILTER — PRESSURE
TIME ZERO

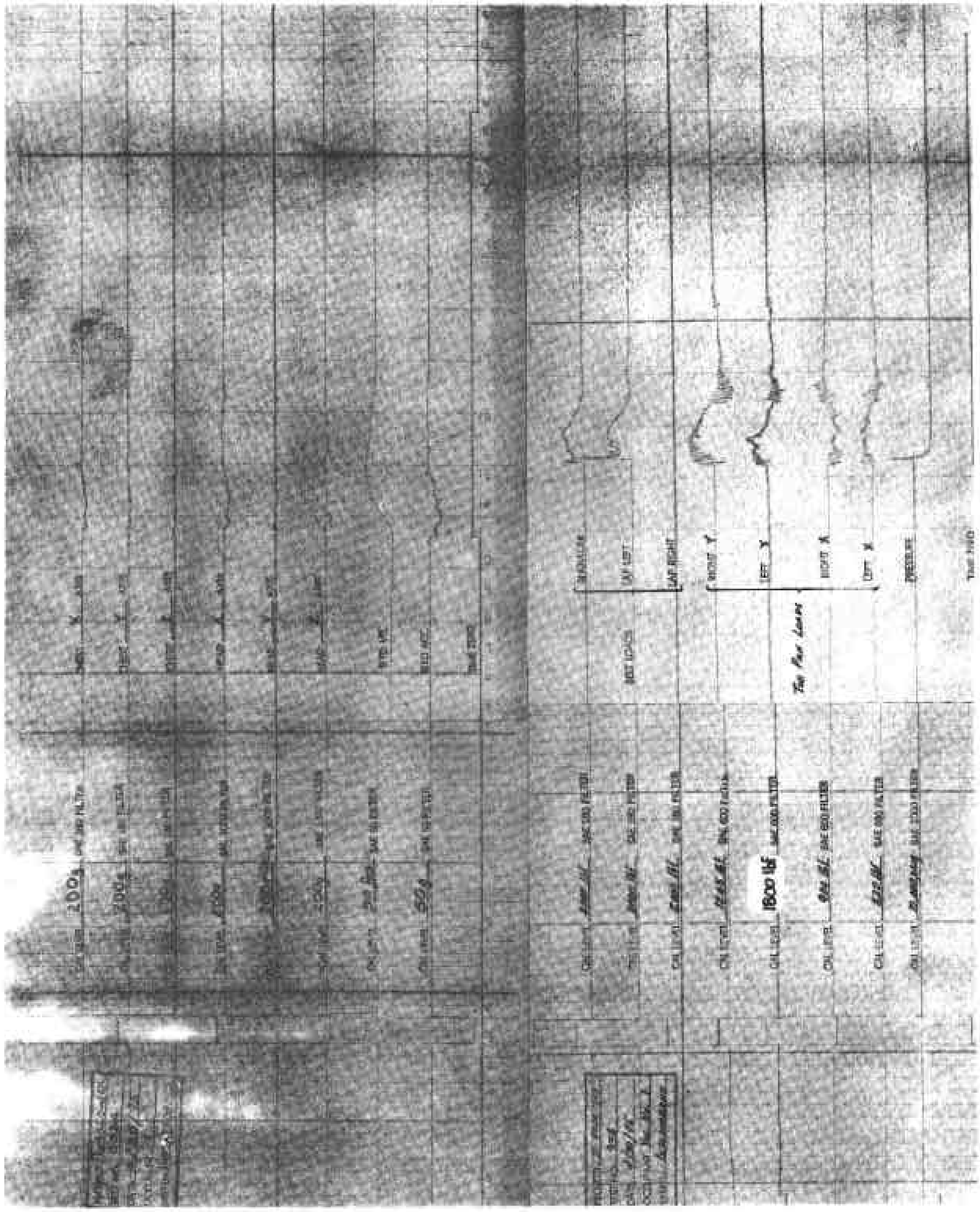


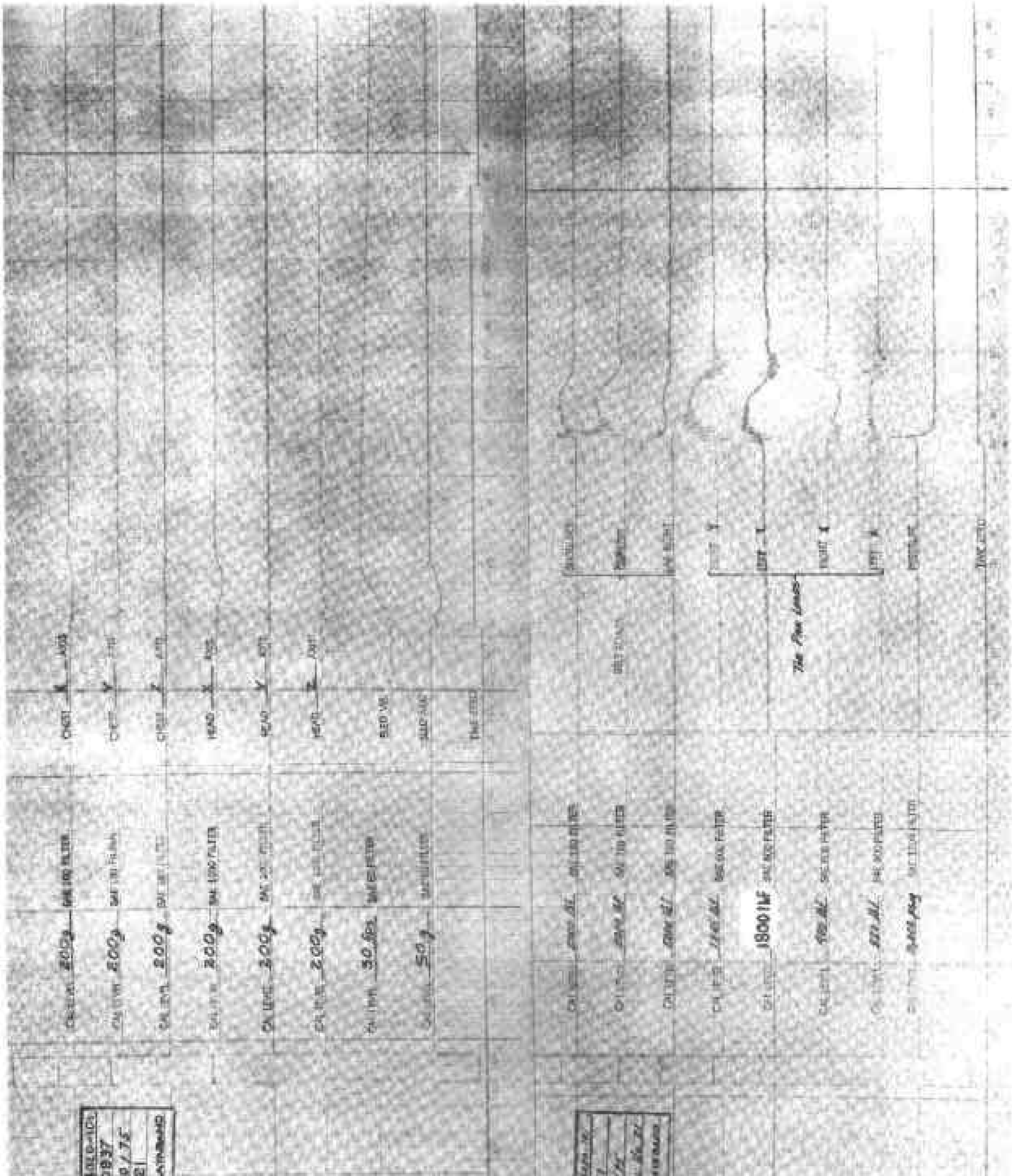
D-21

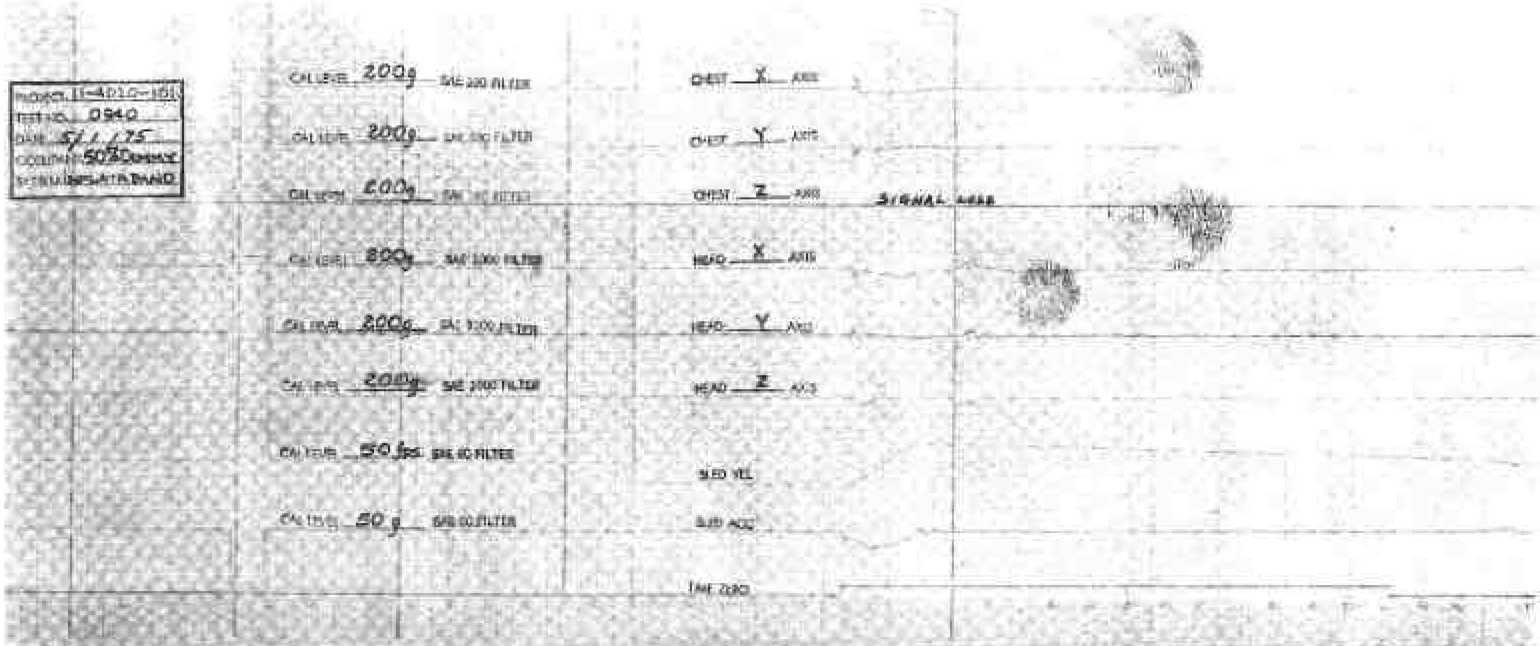


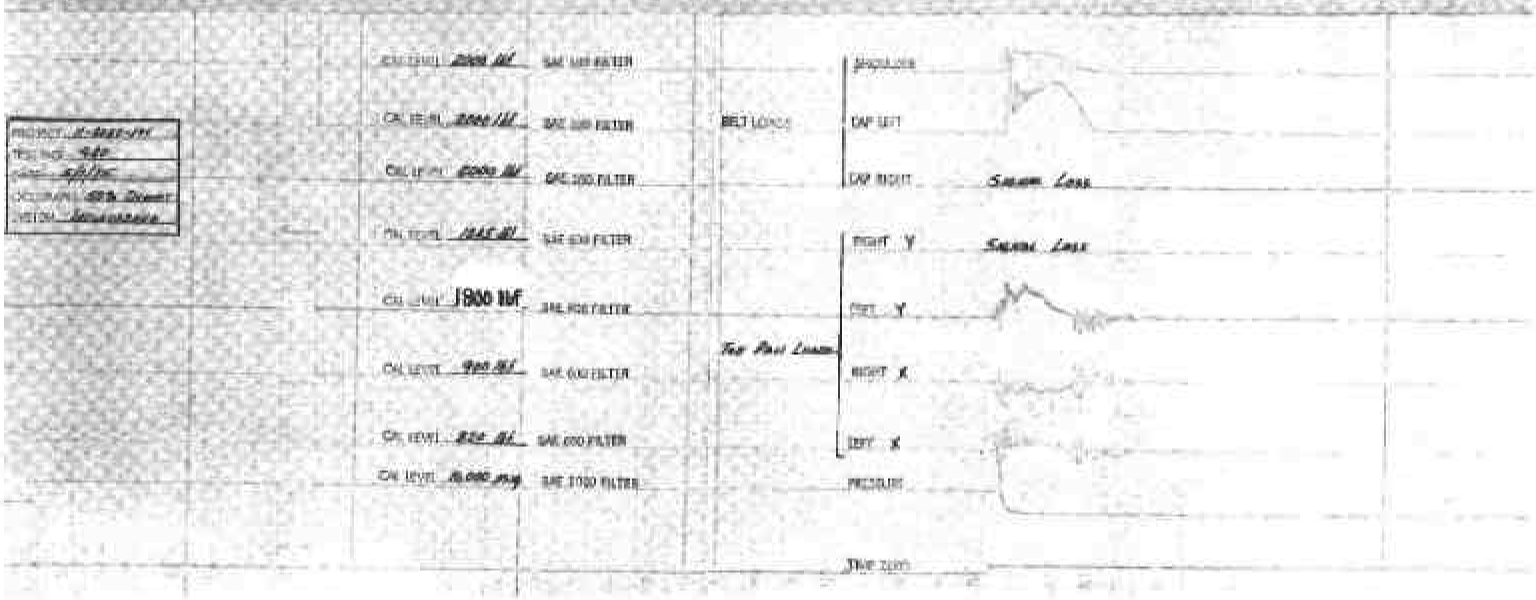

CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
SLED VEL
SLED ACC
TIME ZERO
CAL LEVEL 200g
CAL LEVEL 50 fps
CAL LEVEL 50g
SHOULDER
LAP LEFT
LAP RIGHT
RIGHT Y
LEFT Y
RIGHT X
LEFT X
PRESSURE
TIME ZERO
CAL LEVEL 1800 lbf
The Pan Loads

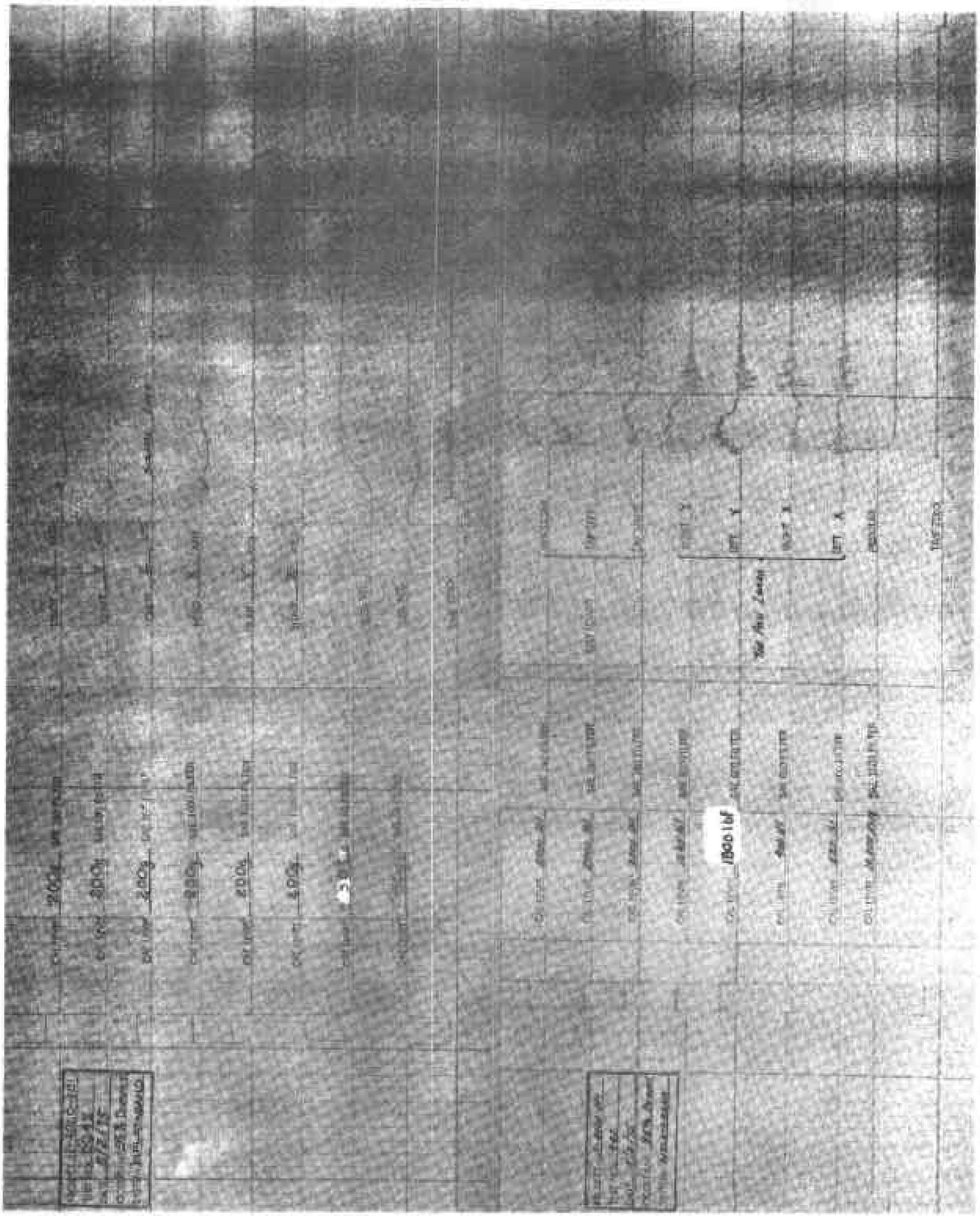

PROJECT 11-4020-101
TEST NO. 0932
DATE 8/29/75
CAL LEVEL 200g SAE 1000 FILTER
CAL LEVEL 50g SAE 60 FILTER
CHEST X
CHEST Y
CHEST Z
HEAD X
HEAD Y
HEAD Z
TIME ZERO
1800 lbf
Tor Pan Loads

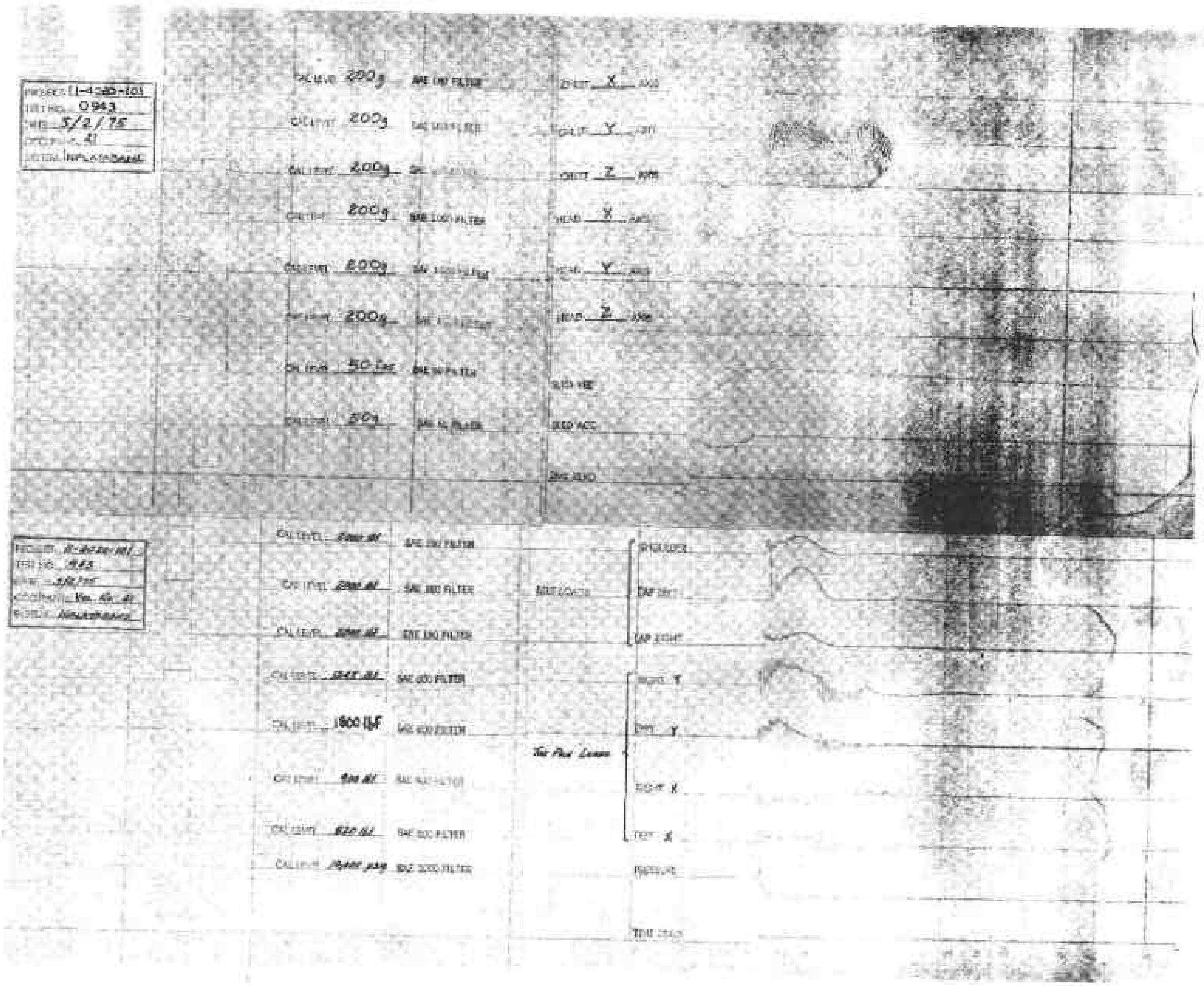


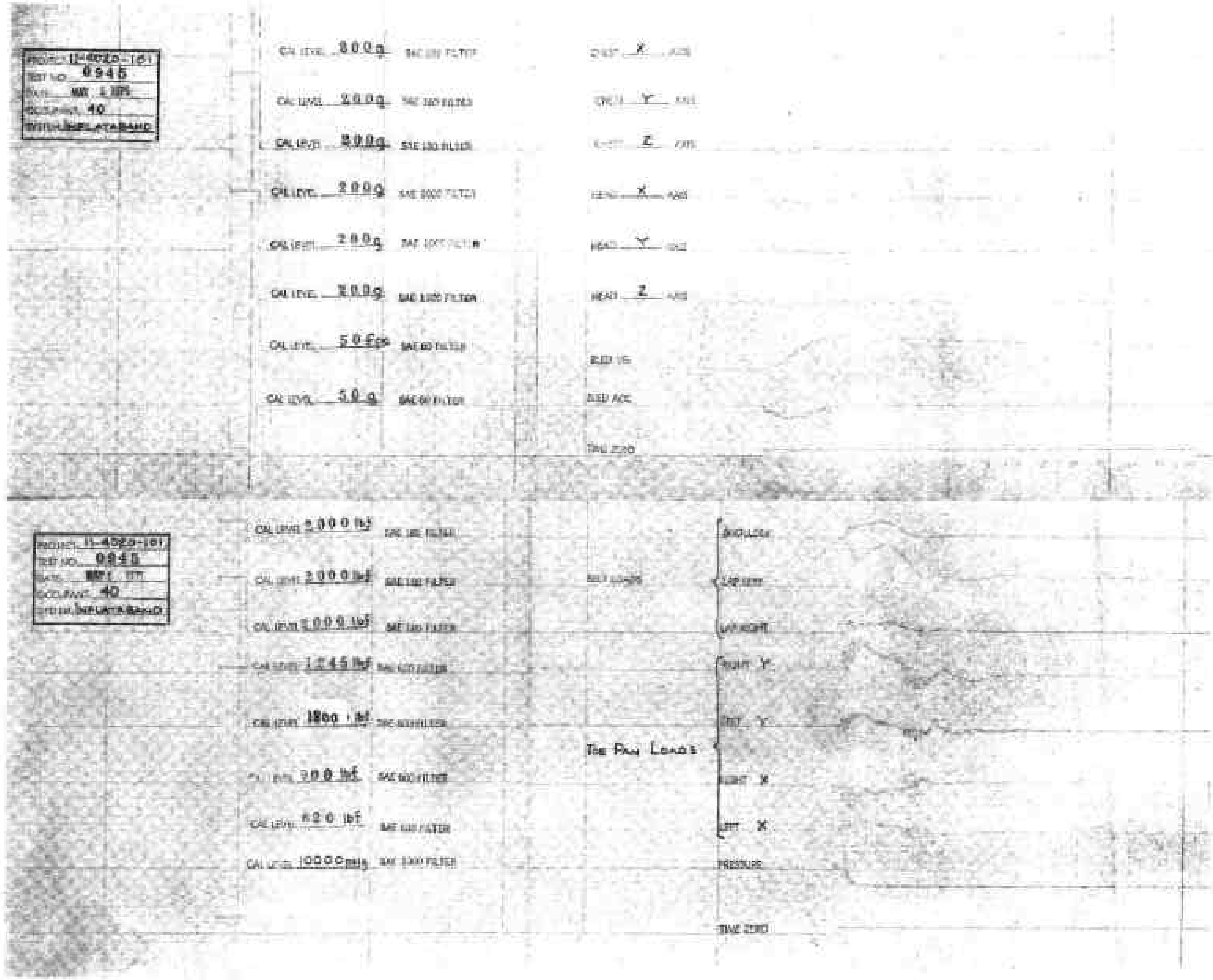


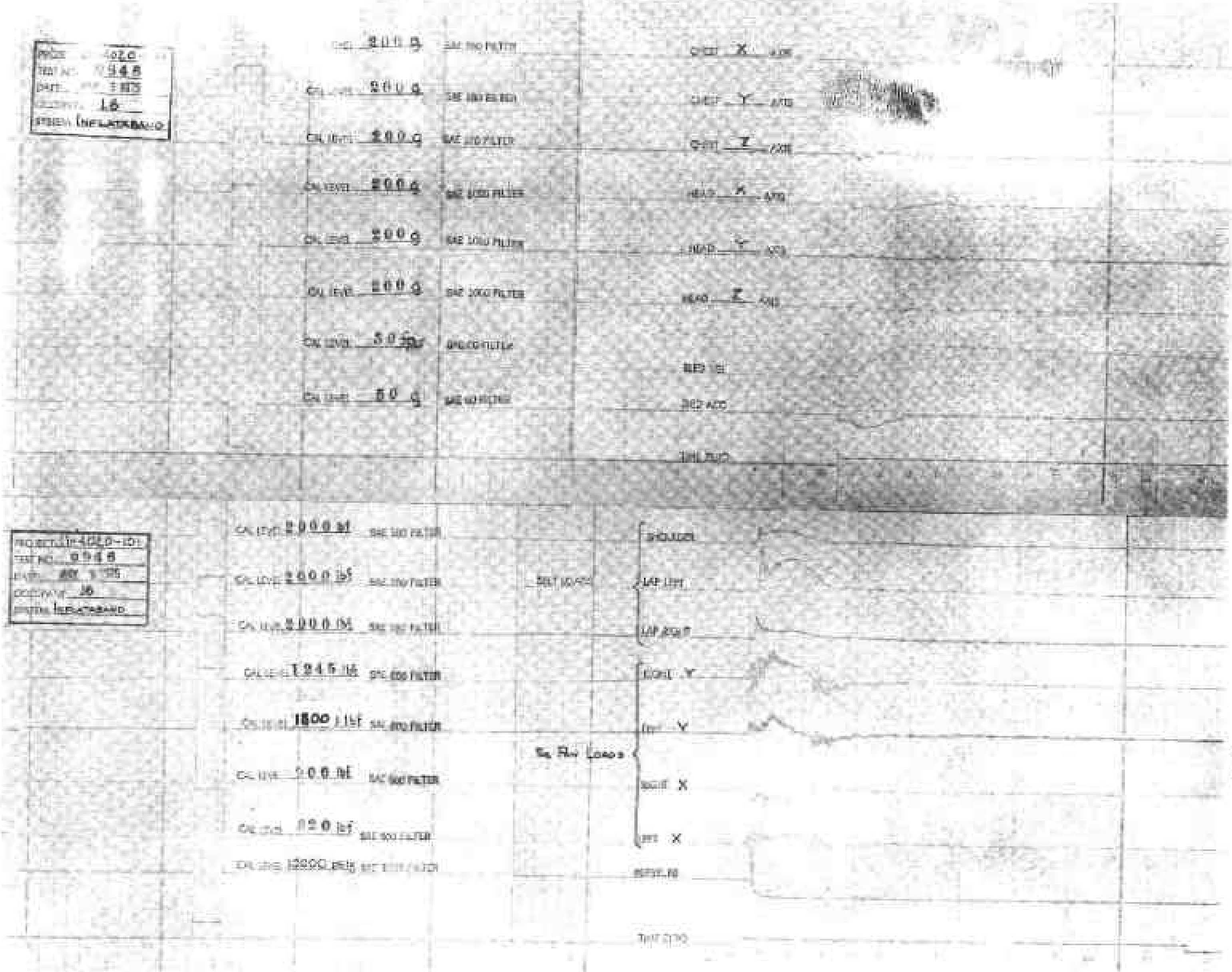

PROJECT 11-4010-151
TEST NO. 0940
DATE 5/1/75
OCCUPANT 50% Dummy
CAL LEVEL 200g SAE 200 FILTER
CHEST X AXIS
CAL LEVEL 200g
CHEST Y AXIS
CHEST Z AXIS
SIGNAL LOSS
CAL LEVEL 800g
HEAD X AXIS
CAL LEVEL 800g
HEAD Y AXIS
CAL LEVEL 200g SAE 2000 FILTER
HEAD Z AXIS
CAL LEVEL 50 fps SAE 60 FILTER
SLED VEL
CAL LEVEL 50 g SAE 60 FILTER
SLED ACC
TIME ZERO

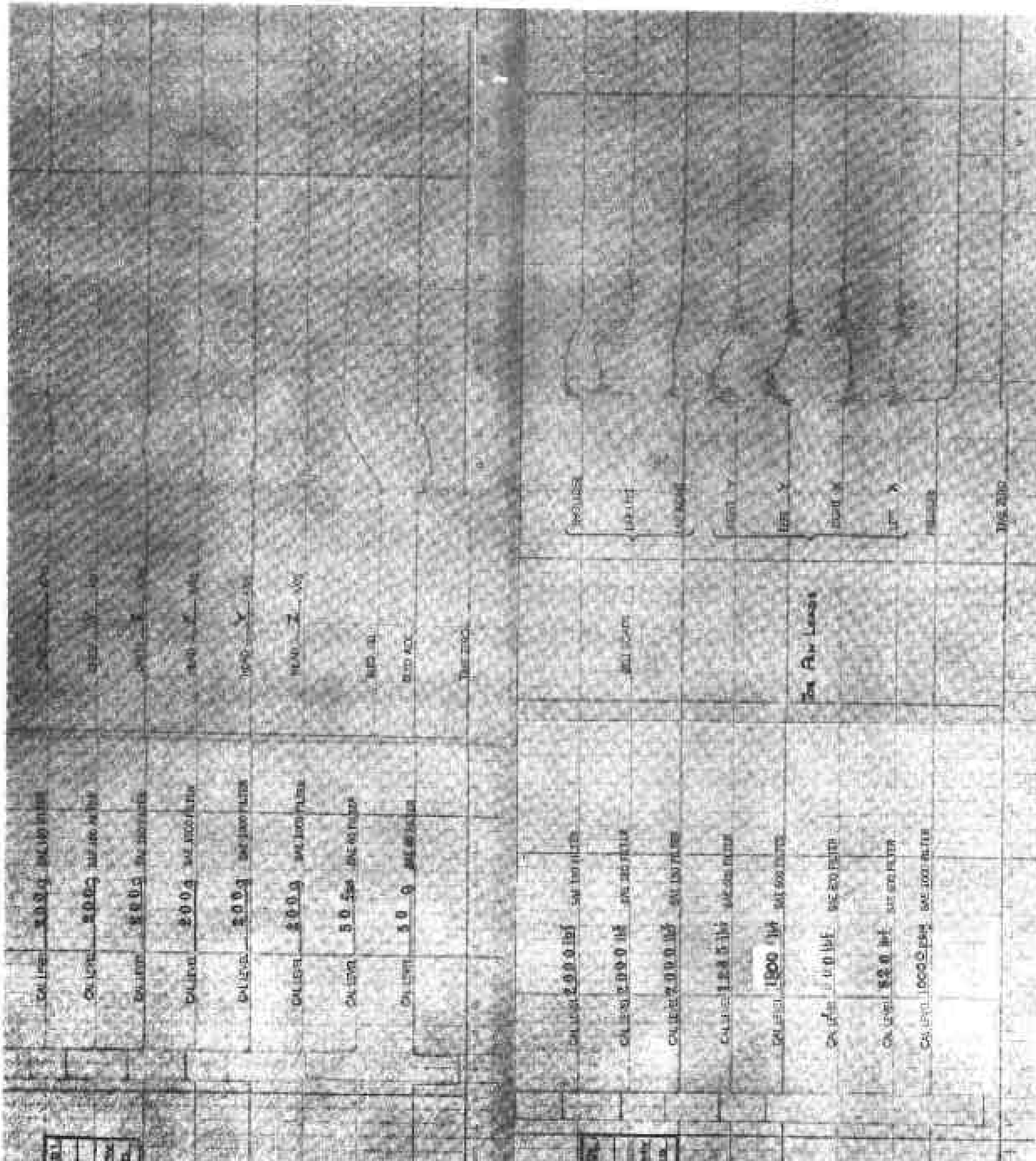

SAE 600 FILTER
BELT LOADS
SHOULDER
LAP LEFT
SAE 200 FILTER
LAP RIGHT
Signal Loss
SAE 600 FILTER
RIGHT Y
Signal Loss
CAL LEVEL 1800 lbf
LEFT Y
RIGHT X
SAE 600 FILTER
LEFT X
SAE 600 FILTER
SAE 1000 FILTER
PRESSURE
TIME ZERO

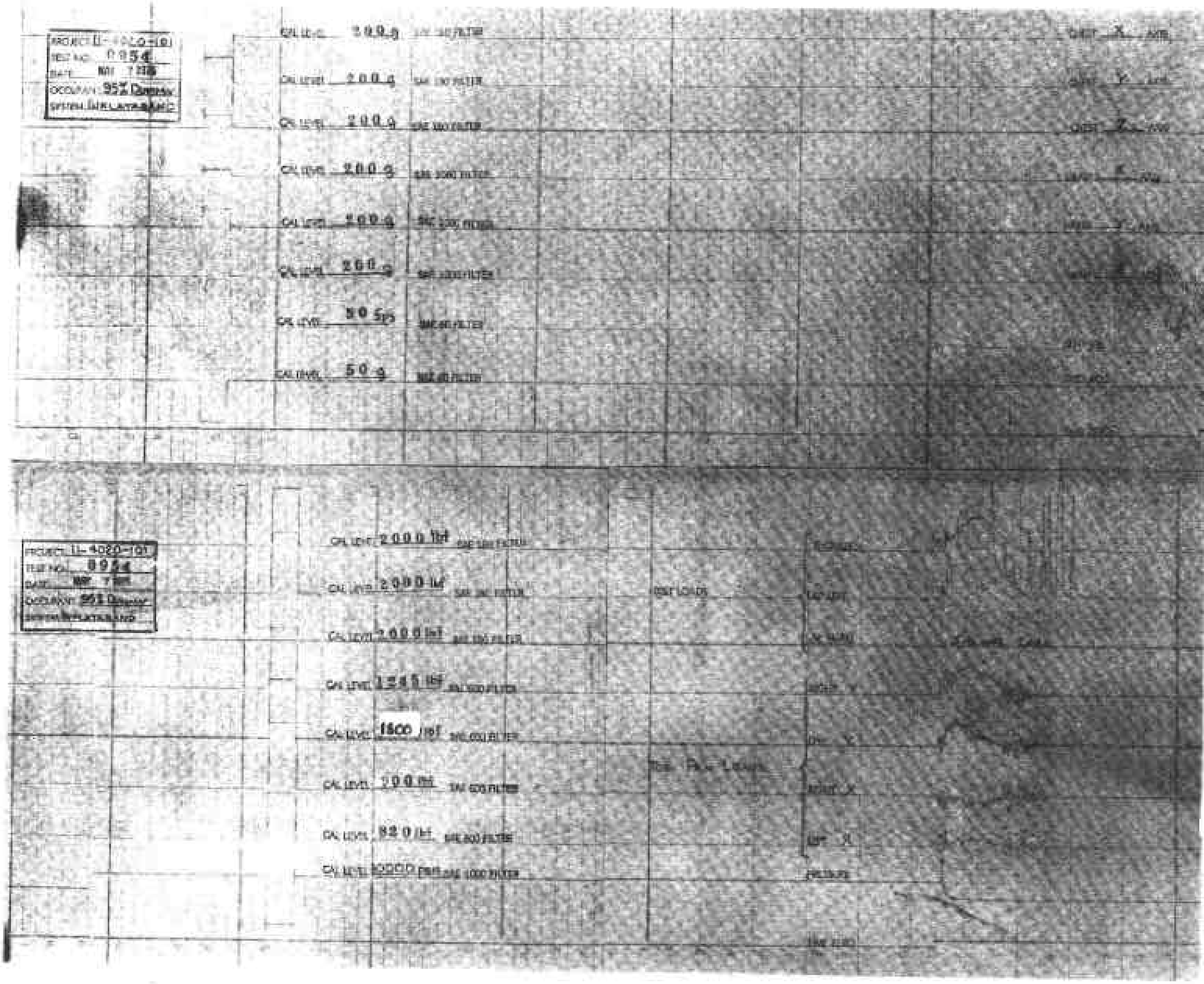

200g
300g
200g
200g
200g
1800 lbf


PROJECT 11-4020-101
TEST NO. 0943
DATE 5/2/75
SPECIMEN 41
CAL LEVEL 200g
CHEST X ACC
CHEST Y ACC
CHEST Z ACC
HEAD X ACC
HEAD Y ACC
HEAD Z ACC
CAL LEVEL 50g
SLED ACC
1800 LBF
SHOULDER
LAP LEFT
LAP RIGHT
Tie Pad Loads
RIGHT X
TEMP

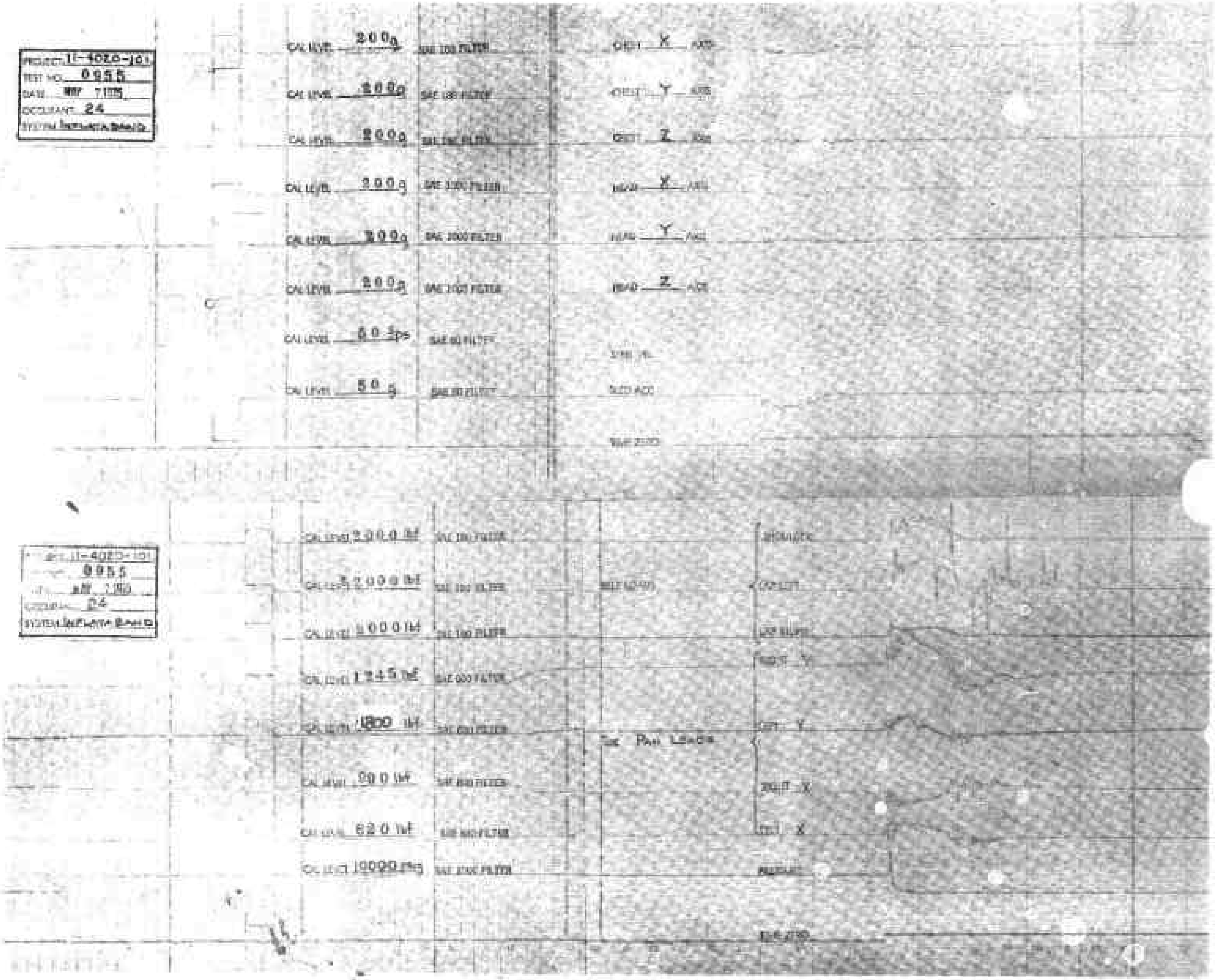

PROJECT 11-4020-101
TEST NO. 0945
OCCUPANT 40
SYSTEM INFLATABAND
CAL LEVEL 200g
CAL LEVEL 200g
CAL LEVEL 200g
CAL LEVEL 200g
CAL LEVEL 200g
CAL LEVEL 50 fps
CAL LEVEL 50 g
CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
SLED VEL
SLED ACC
TIME ZERO
PROJECT 11-4020-101
TEST NO. 0945
OCCUPANT 40
SYSTEM INFLATABAND
CAL LEVEL 2000 lbf
CAL LEVEL 2000 lbf
CAL LEVEL 2000 lbf
CAL LEVEL 1245 lbf
CAL LEVEL 1800 lbf
CAL LEVEL 300 lbf
CAL LEVEL 420 lbf
CAL LEVEL 10000 psig
BELT LOADS
SHOULDER
LAP LEFT
LAP RIGHT
The Pan Loads
RIGHT Y
LEFT Y
RIGHT X
LEFT X
PRESSURE
TIME ZERO


CAL LEVEL 200 g
CAL LEVEL 50 g
CHEST X ACC
CHEST Y ACC
CHEST Z ACC
HEAD X ACC
HEAD Y ACC
HEAD Z ACC
INFLATABAND
CAL LEVEL 2000 lbf
SHOULDER
LAP LEFT
LAP RIGHT
CAL LEVEL 1800 lbf
CAL LEVEL 12000 psig

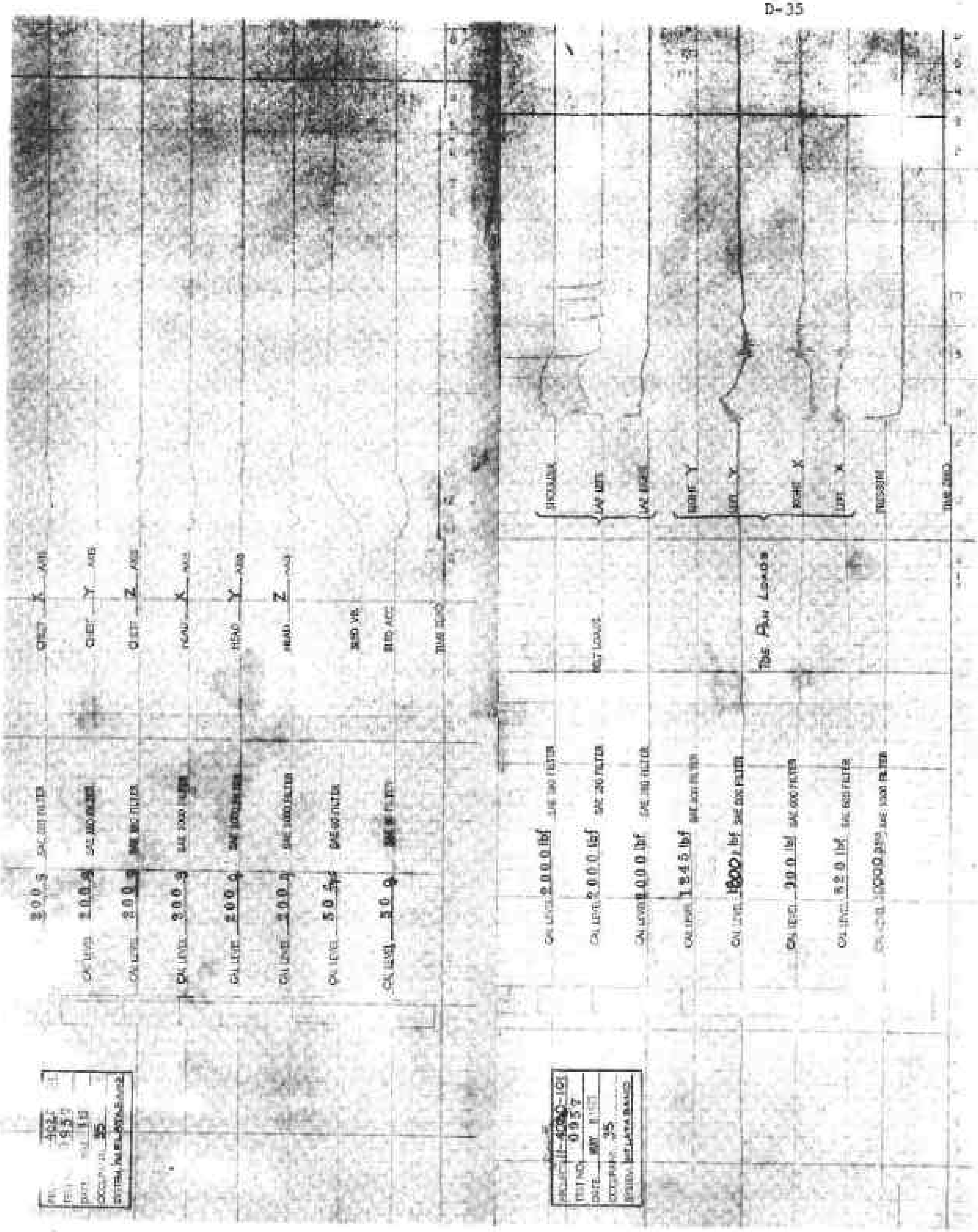




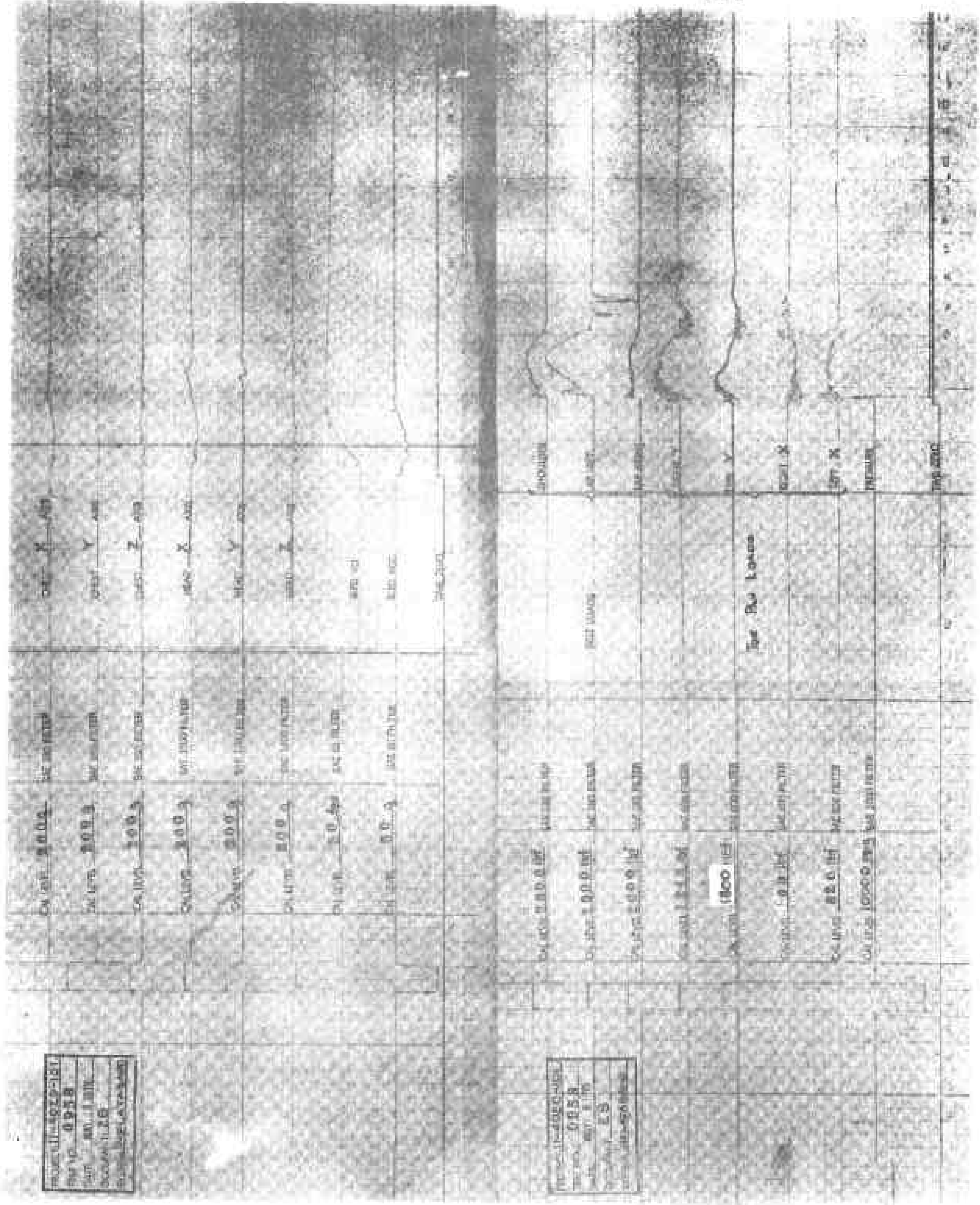
TEST NO. 0954
OCCUPANT 95% Dummy
CAL LEVEL 200.0 g
CAL LEVEL 200.0 g
CAL LEVEL 200.0 g
CAL LEVEL 200.0 g
CAL LEVEL 200.0 g
CAL LEVEL 200.0 g
CAL LEVEL 50.5 g
CAL LEVEL 50.0 g
CHEST X
CHEST Y
CHEST Z
TEST NO. 0954
OCCUPANT 95% Dummy
CAL LEVEL 2000 lbf
CAL LEVEL 2000 lbf
CAL LEVEL 2000 lbf
CAL LEVEL 1545 lbf
CAL LEVEL 1500 lbf
CAL LEVEL 200.0 lbf
CAL LEVEL 820 lbf
CAL LEVEL 1000.0 PSI
TEST LOADS

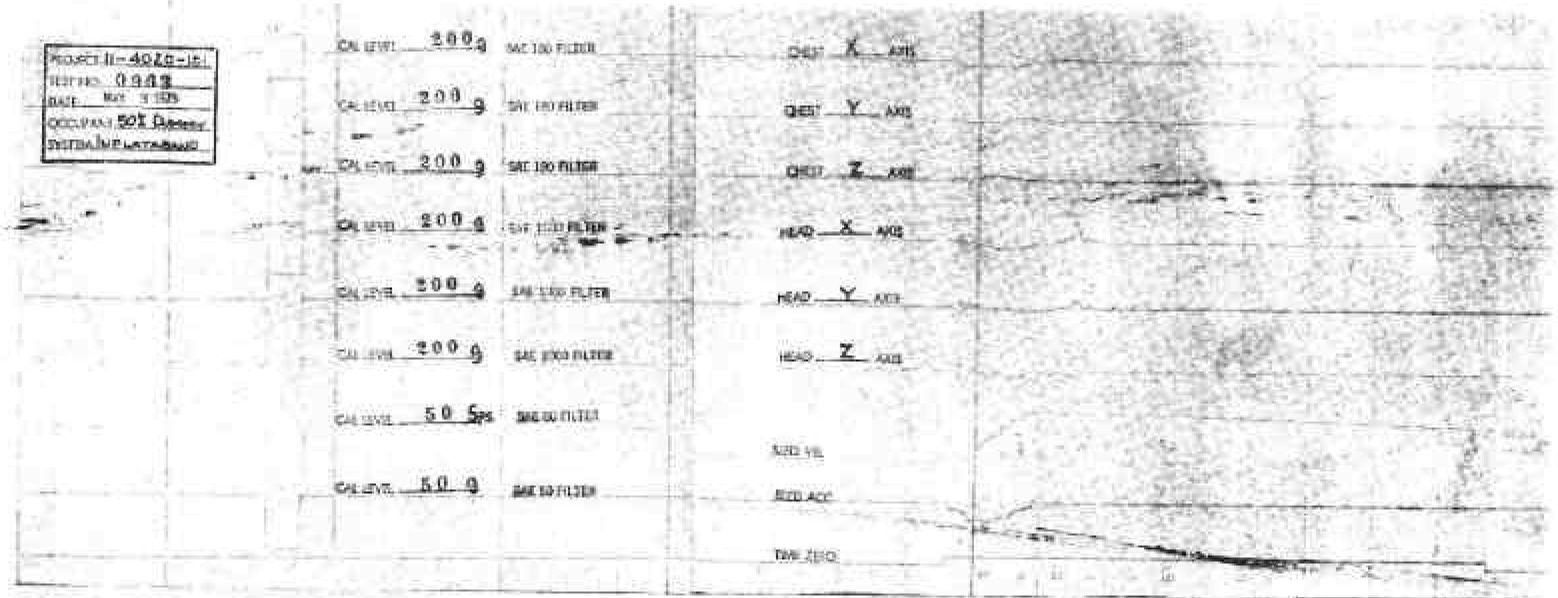
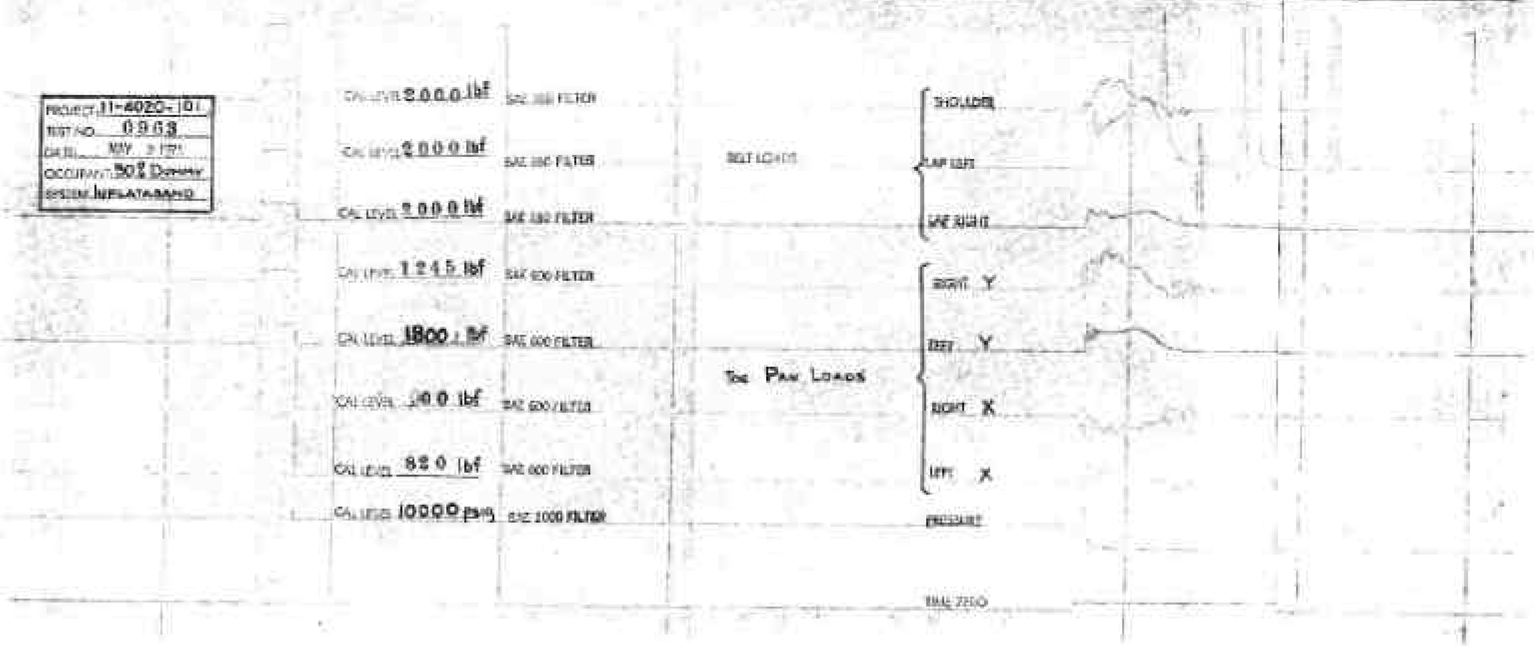


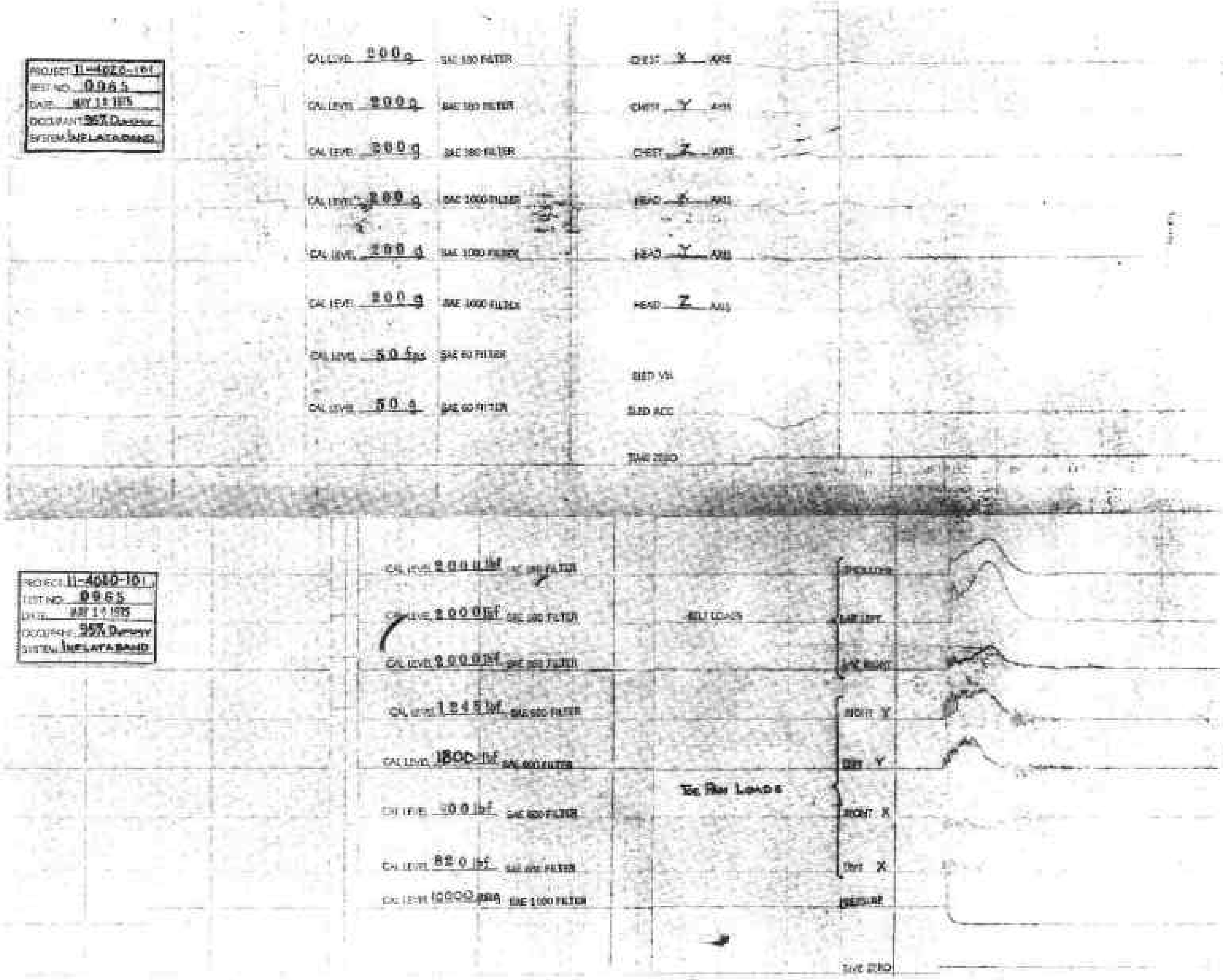
PROJECT 11-4020-101
TEST NO. 0955
DATE MAY 7 1975
OCCUPANT 24
SYSTEM INFLATABAND
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 60 fps
CAL LEVEL 50 g
CHEST X ACC
CHEST Y ACC
CHEST Z ACC
HEAD X ACC
HEAD Y ACC
HEAD Z ACC
SLED ACC
11-4020-101
0955
24
SYSTEM INFLATABAND
CAL LEVEL 2000 lbf
CAL LEVEL 2000 lbf
CAL LEVEL 2000 lbf
CAL LEVEL 1245 lbf
CAL LEVEL 1800 lbf
CAL LEVEL 900 lbf
CAL LEVEL 620 lbf
CAL LEVEL 10000 psig
BELT LOADS
PAN LOADS
RIGHT Y
LEFT Y
RIGHT X
LEFT X

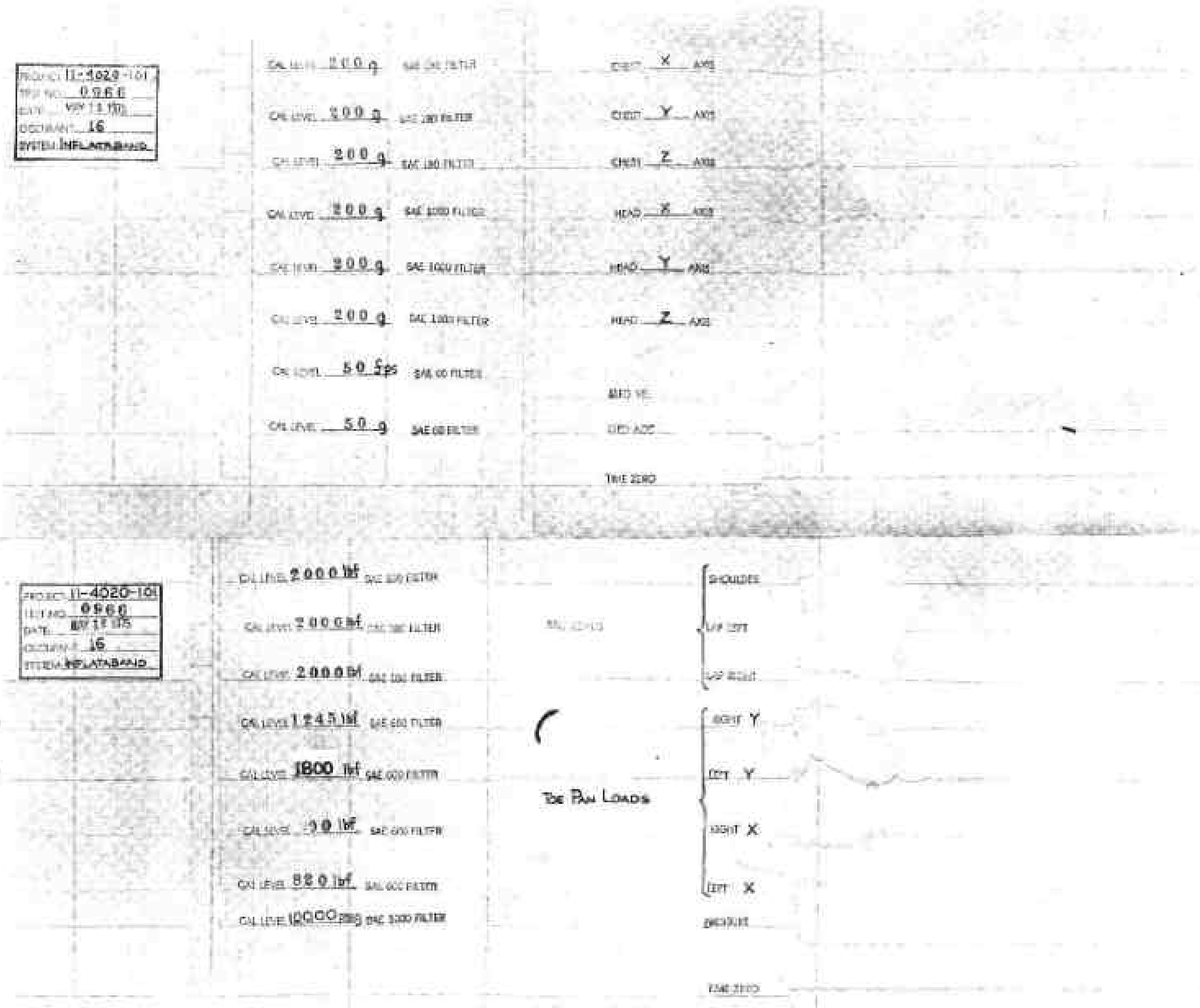


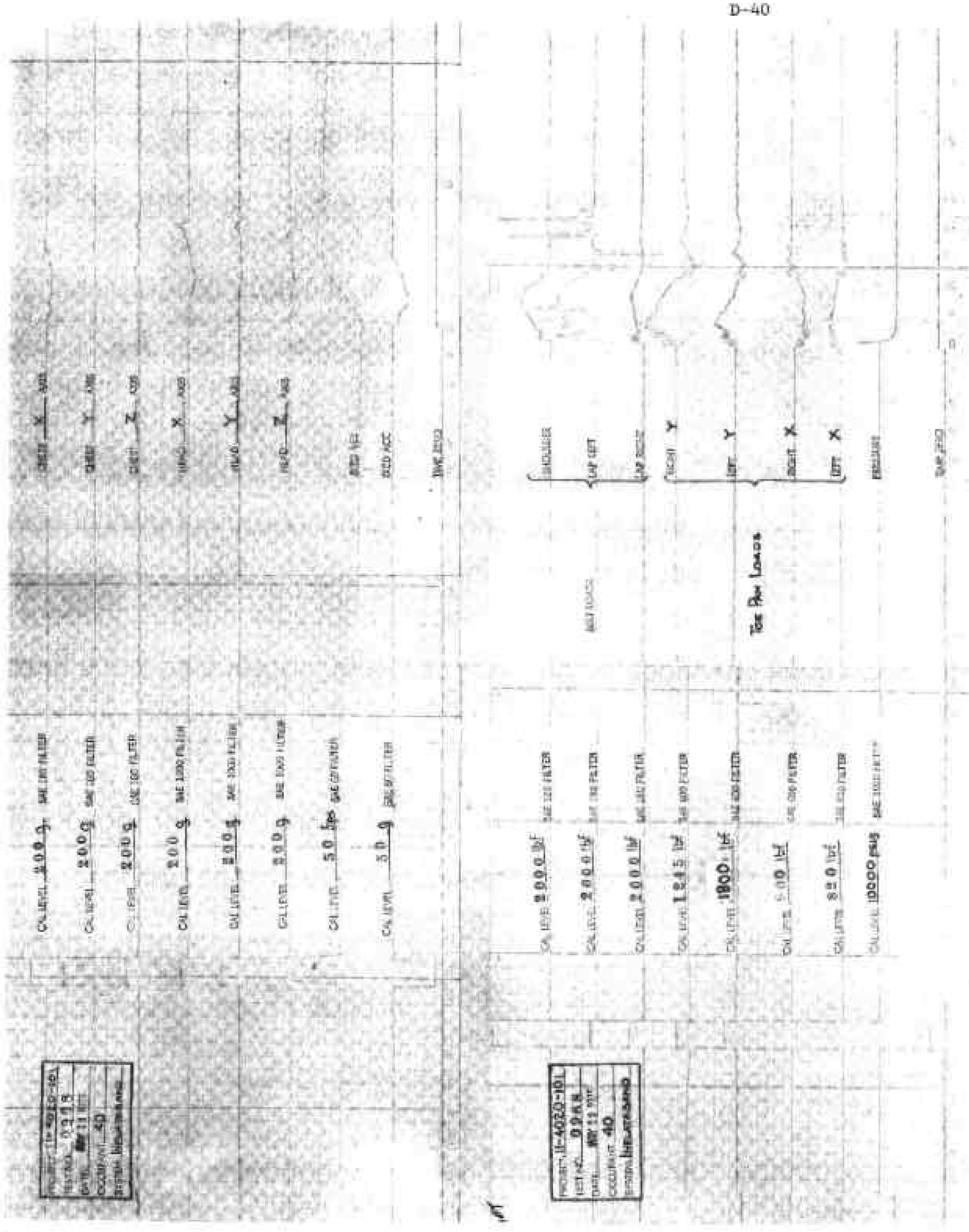
TEST NO. 0957
OCCUPANT 35
CAL LEVEL 200 g
CAL LEVEL 50 g
CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
SLED VEL.
SLED ACC.
TIME ZERO
CAL LEVEL 2000 lbf
CAL LEVEL 1845 lbf
CAL LEVEL 1800 lbf
CAL LEVEL 300 lbf
CAL LEVEL 520 lbf
BELT LOADS
SHOULDER
LAP LEFT
LAP RIGHT
TOE PAN LOADS
RIGHT Y
LEFT Y
RIGHT X
LEFT X
PRESSURE
TIME ZERO

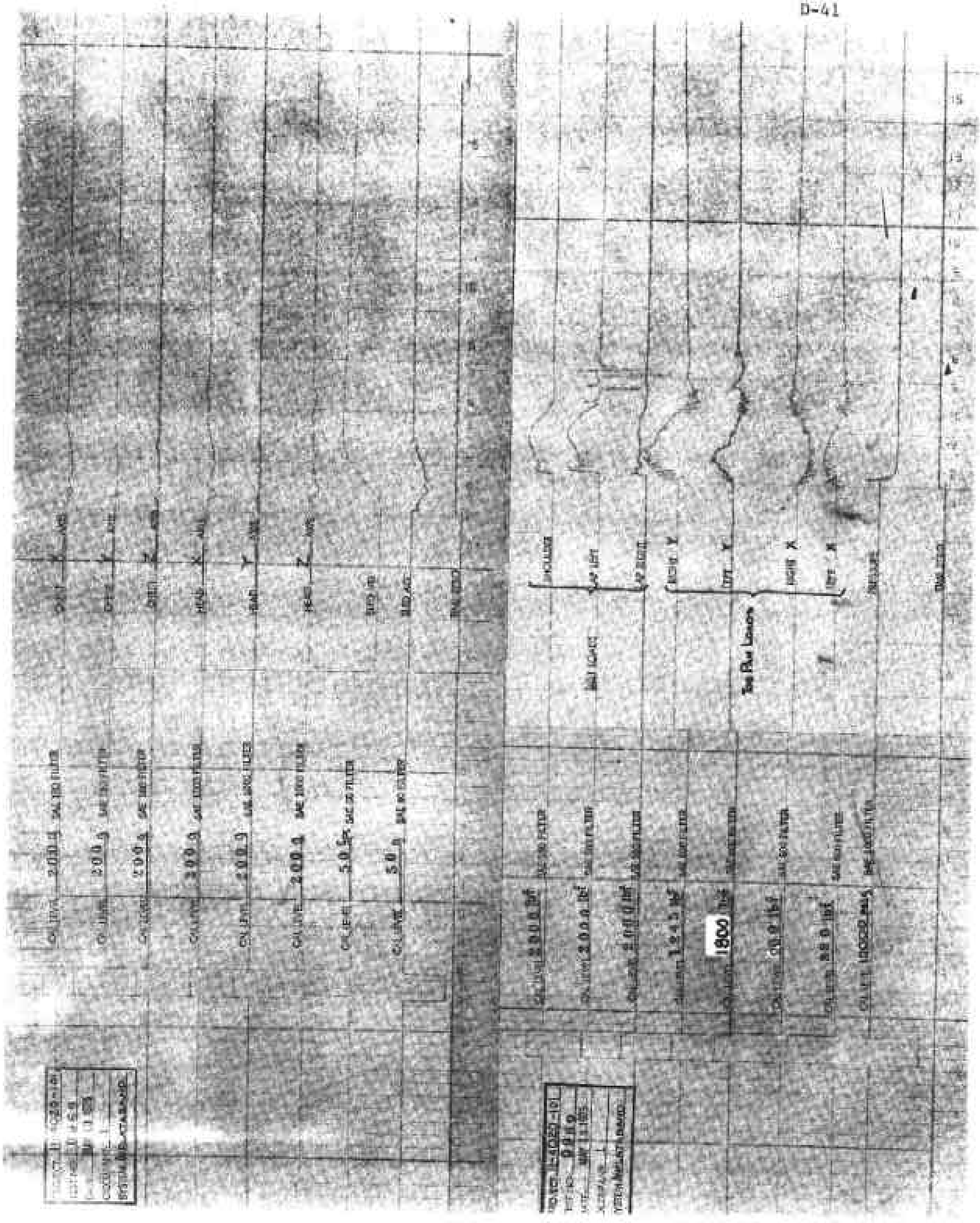

0958
CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
1800 lbf
SHOULDER
RIGHT X
PRESSURE

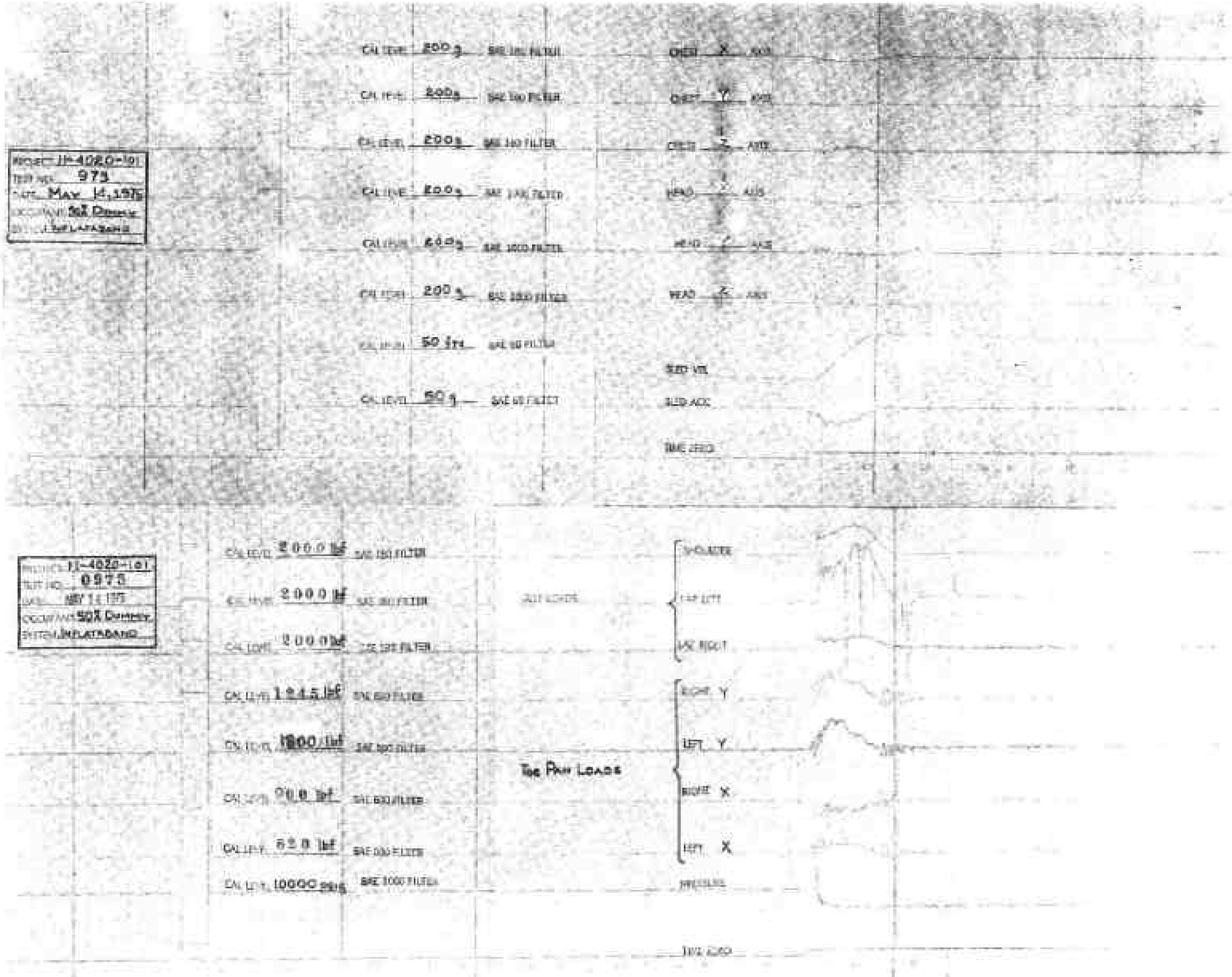

PROJECT 11-4020-101
TEST NO. 0963
DATE MAY 9 1971
OCCUPANT 50% Dummy
SYSTEM INFLATABAND
CAL LEVEL 200 g SAE 180 FILTER
CAL LEVEL 200 g SAE 180 FILTER
CAL LEVEL 200 g SAE 180 FILTER
CAL LEVEL 200 g SAE 1000 FILTER
CAL LEVEL 200 g SAE 1000 FILTER
CAL LEVEL 200 g SAE 1000 FILTER
CAL LEVEL 50 fps SAE 60 FILTER
CAL LEVEL 50 g SAE 60 FILTER
CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
SLED VEL
SLED ACC
TIME ZERO

PROJECT 11-4020-101
TEST NO. 0963
DATE MAY 9 1971
OCCUPANT 50% Dummy
SYSTEM INFLATABAND
CAL LEVEL 2000 lbf SAE 180 FILTER
CAL LEVEL 2000 lbf SAE 180 FILTER
CAL LEVEL 2000 lbf SAE 180 FILTER
CAL LEVEL 1245 lbf SAE 600 FILTER
CAL LEVEL 1800 lbf SAE 600 FILTER
CAL LEVEL 820 lbf SAE 600 FILTER
CAL LEVEL 10000 psig SAE 1000 FILTER
BELT LOADS
SHOULDER
LAP LEFT
LAP RIGHT
TOE PAN LOADS
RIGHT Y
LEFT Y
RIGHT X
LEFT X
PRESSURE
TIME ZERO


PROJECT 11-4020-101
TEST NO. 0965
DATE MAY 14 1975
OCCUPANT 95% Dummy
SYSTEM INFLATABAND
CAL LEVEL 200 g SAE 180 FILTER
CAL LEVEL 200 g SAE 180 FILTER
CAL LEVEL 200 g SAE 180 FILTER
CAL LEVEL 200 g SAE 1000 FILTER
CAL LEVEL 200 g SAE 1000 FILTER
CAL LEVEL 200 g SAE 1000 FILTER
CAL LEVEL 50 fps SAE 60 FILTER
CAL LEVEL 50 g SAE 60 FILTER
CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
SLED VEL
SLED ACC
TIME ZERO
PROJECT 11-4020-101
TEST NO. 0965
DATE MAY 14 1975
OCCUPANT 95% Dummy
SYSTEM INFLATABAND
CAL LEVEL 2000 lbf SAE 600 FILTER
CAL LEVEL 2000 lbf SAE 600 FILTER
CAL LEVEL 2000 lbf SAE 600 FILTER
CAL LEVEL 1245 lbf SAE 600 FILTER
CAL LEVEL 1800 lbf SAE 600 FILTER
CAL LEVEL 900 lbf SAE 600 FILTER
CAL LEVEL 820 lbf SAE 600 FILTER
CAL LEVEL 10000 psia SAE 1000 FILTER
BELT LOADS
SHOULDER
LAP LEFT
LAP RIGHT
TOE PAN LOADS
RIGHT Y
LEFT Y
RIGHT X
LEFT X
PRESSURE
TIME ZERO


PROJECT 11-4020-101
TEST NO. 0966
DATE MAY 15 1975
OCCUPANT 16
SYSTEM INFLATABAND
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 50 fps
CAL LEVEL 50 g
CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
TIME ZERO
PROJECT 11-4020-101
TEST NO. 0966
DATE MAY 15 1975
OCCUPANT 16
SYSTEM INFLATABAND
CAL LEVEL 2000 lbf
CAL LEVEL 2000 lbf
CAL LEVEL 2000 lbf
CAL LEVEL 1245 lbf
CAL LEVEL 1800 lbf
CAL LEVEL 90 lbf
CAL LEVEL 880 lbf
CAL LEVEL 10000
SHOULDER
LAP LEFT
LAP RIGHT
RIGHT Y
LEFT Y
RIGHT X
LEFT X
PRESSURE
TIME ZERO
Toe Pan Loads


Toe Pan Loads



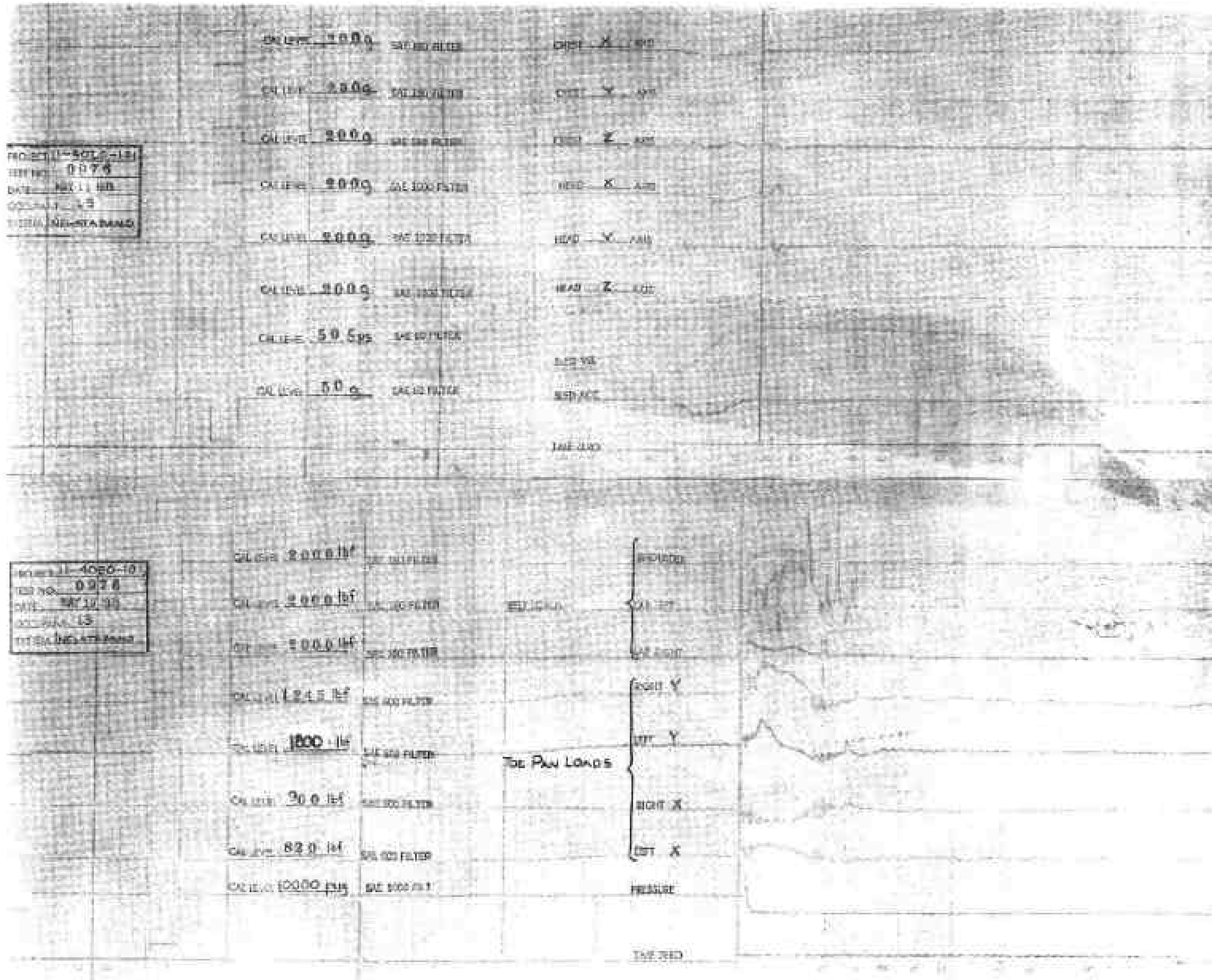

PROJECT 11-4020-101
TEST NO. 973
DATE MAY 14, 1975
OCCUPANT 50% DUMMY
SYSTEM INFLATABAND
CAL LEVEL 200 g SAE 180 FILTER
CAL LEVEL 200 g SAE 180 FILTER
CAL LEVEL 200 g SAE 180 FILTER
CAL LEVEL 200 g SAE 1000 FILTER
CAL LEVEL 200 g SAE 1000 FILTER
CAL LEVEL 200 g SAE 1000 FILTER
CAL LEVEL 50 fps SAE 60 FILTER
CAL LEVEL 50 g SAE 60 FILTER
CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
SLED VEL
SLED ACC
TIME ZERO
PROJECT 11-4020-101
TEST NO. 0973
DATE MAY 14 1975
OCCUPANT 50% DUMMY
SYSTEM INFLATABAND
CAL LEVEL 2000 lbf SAE 180 FILTER
CAL LEVEL 2000 lbf SAE 180 FILTER
CAL LEVEL 2000 lbf SAE 180 FILTER
CAL LEVEL 1045 lbf SAE 600 FILTER
CAL LEVEL 1800 lbf SAE 600 FILTER
CAL LEVEL 900 lbf SAE 600 FILTER
CAL LEVEL 820 lbf SAE 600 FILTER
CAL LEVEL 10000 psig SAE 1000 FILTER
BELT LOADS
SHOULDER
LAP LEFT
LAP RIGHT
TOE PAN LOADS
RIGHT Y
LEFT Y
RIGHT X
LEFT X
PRESSURE
TIME ZERO

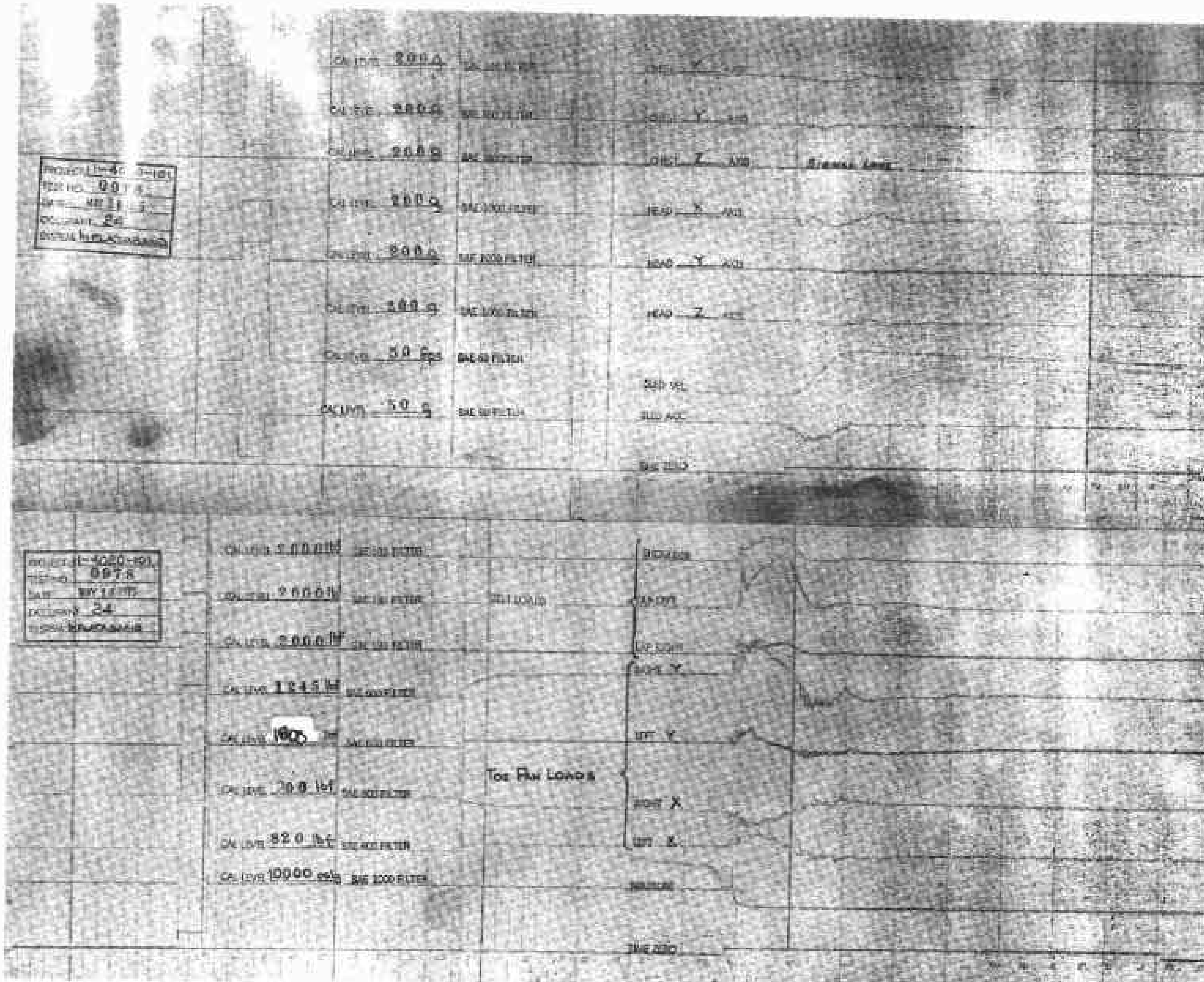
PROJECT 11-1020-101
TEST NO. 0975
DATE [illegible] 1975
SUBJECT 95% DUMMY
SYSTEM INFLATABAND

CAL LEVEL 200 g	SAE [illegible] FILTER	CHEST X ACC	SIGNAL LOSS
CAL LEVEL 200 g	SAE [illegible] FILTER	CHEST Y AXIS	
CAL LEVEL 200 g	SAE [illegible] FILTER	CHEST Z AXIS	SIGNAL LOSS
CAL LEVEL 200 g	SAE 2000 FILTER	HEAD X AXIS	
CAL LEVEL 200 g	SAE 2000 FILTER	HEAD Y AXIS	
CAL LEVEL 200 g	SAE 2000 FILTER	HEAD Z AXIS	
CAL LEVEL 50 fps	SAE 60 FILTER	SLED VEL	
CAL LEVEL 50 g	SAE 60 FILTER	SLED ACC	
		TIME [illegible]	

PROJECT 11-1020-101
TEST NO. 0975
DATE [illegible] 1975
SUBJECT 95% DUMMY
SYSTEM INFLATABAND

CAL LEVEL 2000 lbf	SAE 100 FILTER	BELT LOADS	SHOULDER
CAL LEVEL 2000 lbf	SAE 100 FILTER		LAP LEFT
CAL LEVEL 2000 lbf	SAE 100 FILTER		LAP RIGHT
CAL LEVEL 1245 lbf	SAE 600 FILTER	TIBIA PIN LOADS	RIGHT Y
CAL LEVEL 1800 lbf	SAE 600 FILTER		LEFT Y
CAL LEVEL 700 lbf	SAE 600 FILTER		RIGHT X
CAL LEVEL 820 lbf	SAE 600 FILTER		LEFT X
CAL LEVEL 10000 psig	SAE 1000 FILTER		PRESSURE
			TIME ZERO


CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 200 g
CAL LEVEL 50.5 ps
CAL LEVEL 50 g
SAE 1000 FILTER
SAE 1000 FILTER
CHEST X AXIS
CHEST Y AXIS
CHEST Z AXIS
HEAD X AXIS
HEAD Y AXIS
HEAD Z AXIS
TIME ZERO
0076
CAL LEVEL 2000 lbf
CAL LEVEL 2000 lbf
CAL LEVEL 5000 lbf
CAL LEVEL 1245 lbf
CAL LEVEL 1800 lbf
CAL LEVEL 900 lbf
CAL LEVEL 820 lbf
CAL LEVEL 10000 psig
SAE 600 FILTER
SAE 100 FILTER
TOE PAN LOADS
RIGHT Y
LEFT Y
RIGHT X
LEFT X
PRESSURE
TIME ZERO
11-4050-10
0076
13

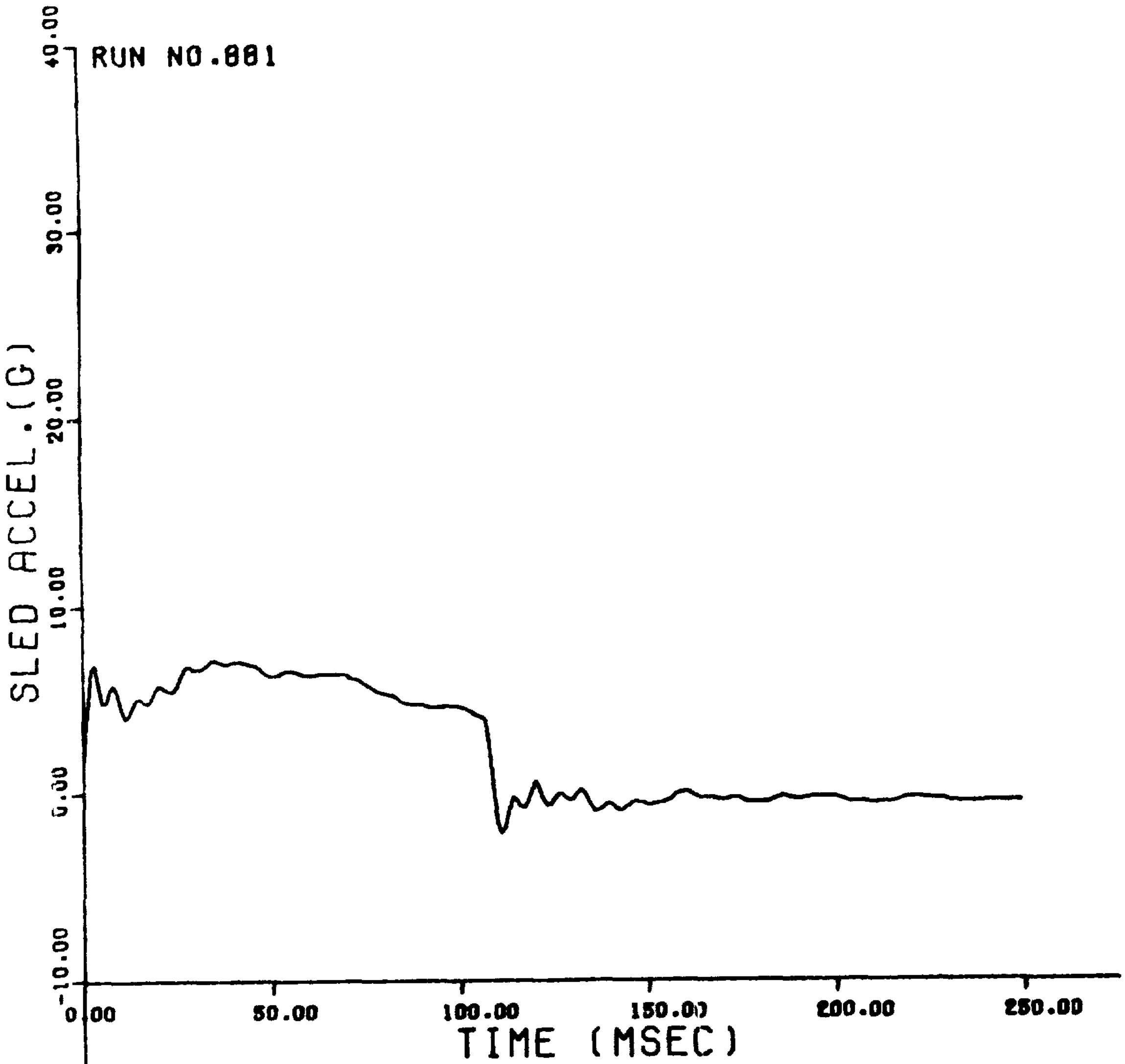


CAL LEVEL 200 G
CAL LEVEL 200 G
CAL LEVEL 200 G
CAL LEVEL 200 G
CAL LEVEL 200 G
CAL LEVEL 200 G
CAL LEVEL 50 fps
CAL LEVEL 50 G
CHEST X
CHEST Y
CHEST Z
HEAD X
HEAD Y
HEAD Z
SLED VEL
SLED ACC
CAL LEVEL 1245 lbf
CAL LEVEL 1800
CAL LEVEL 300 lbf
CAL LEVEL 820 lbf
CAL LEVEL 10000 psig
RIGHT Y
LEFT Y
RIGHT X
LEFT X
TOE PAN LOADS

D-45

APPENDIX E

Production Test Series Computer Plots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30.00
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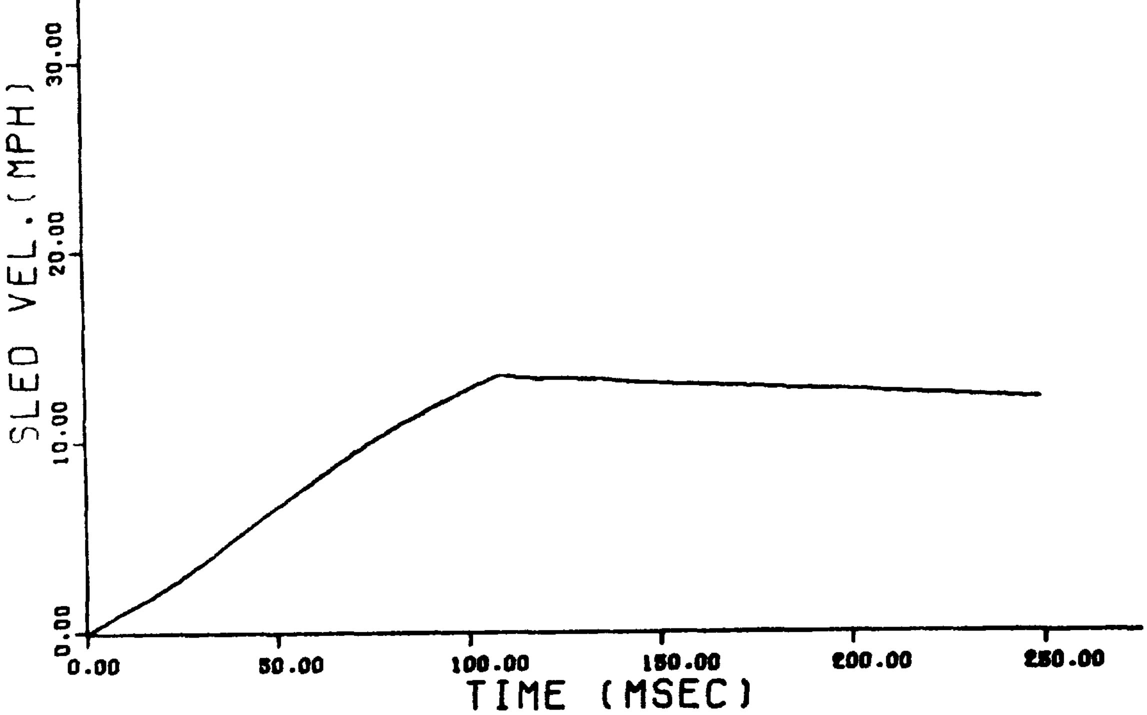
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)


SLED VEL.(MPH)
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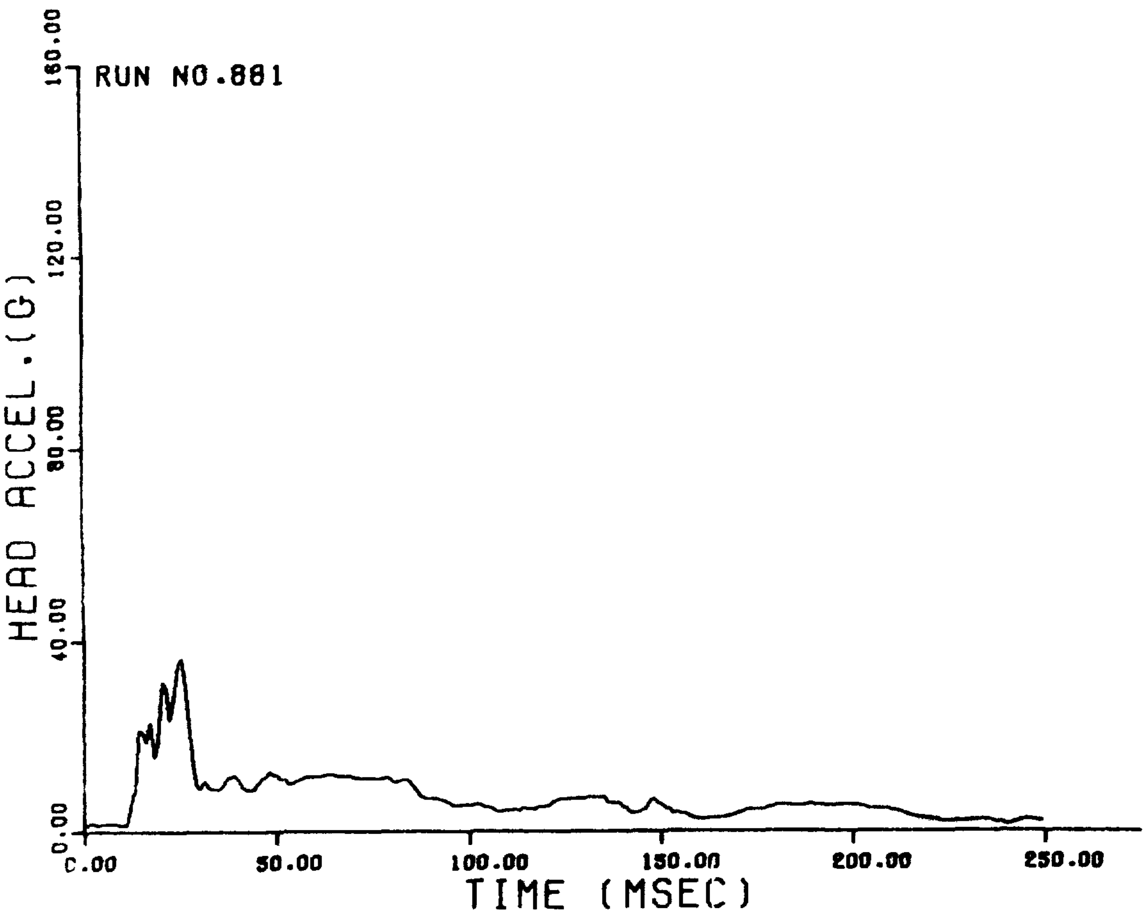
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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HEAD ACCEL.(G)
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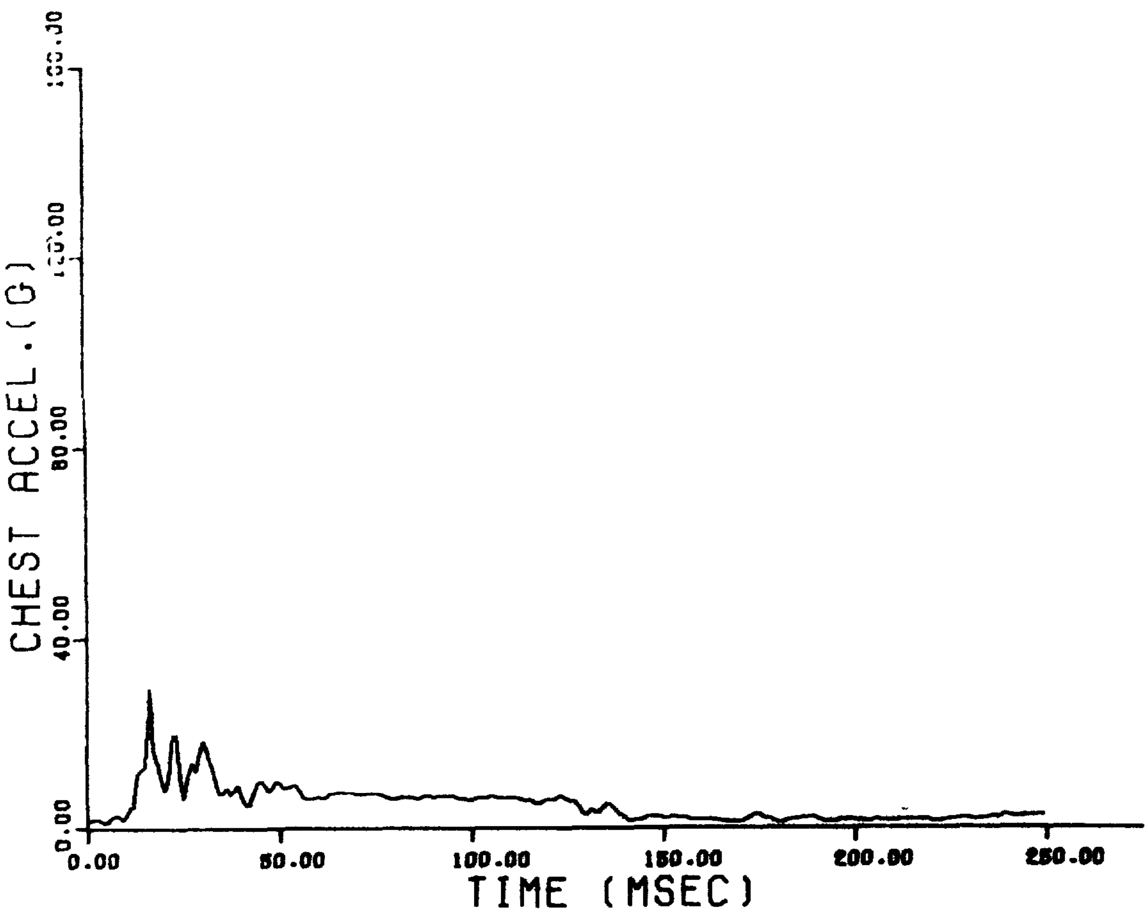
40.00
0.00
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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50.00
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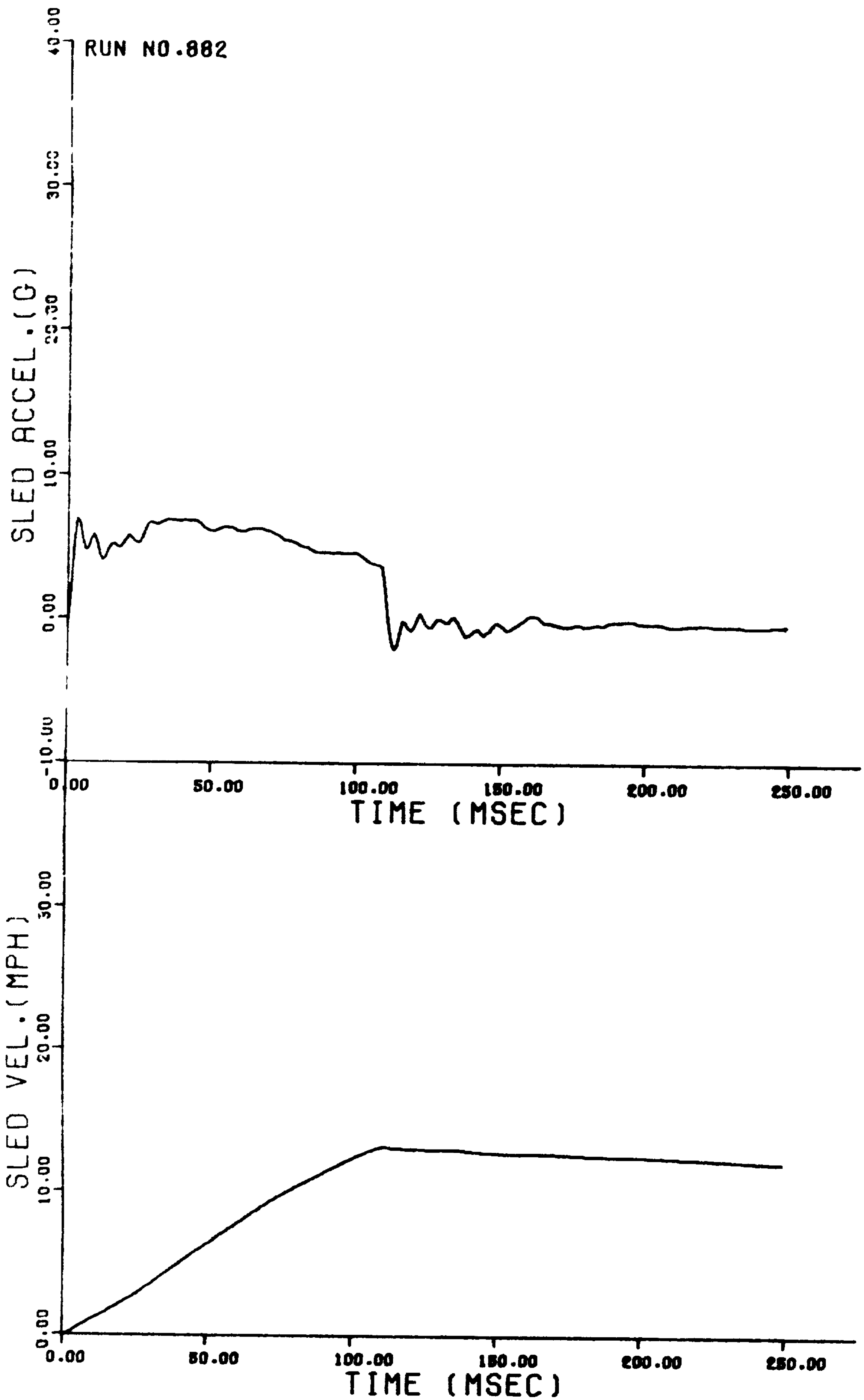
200.00
250.00
TIME (MSEC)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10.00
0.00
-10.00
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)
SLED VEL.(MPH)
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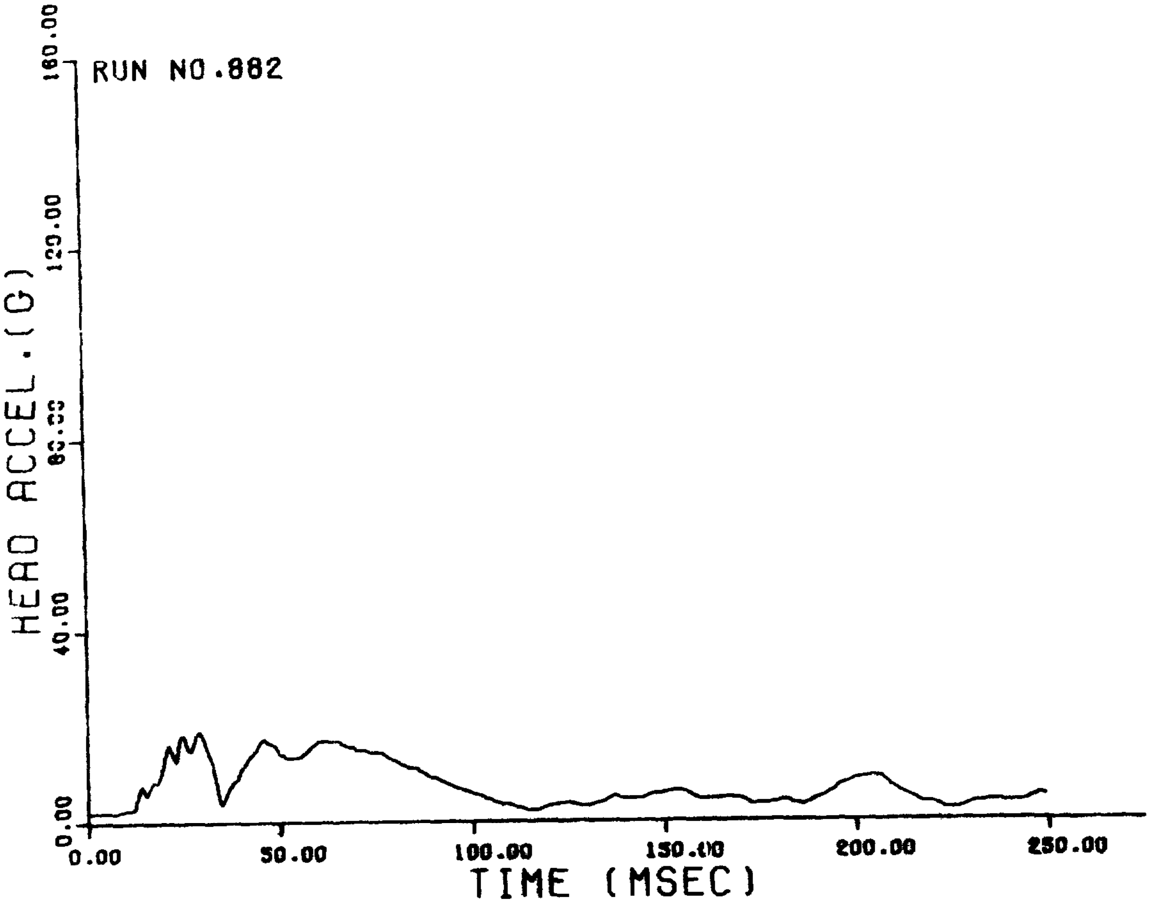
20.00
10.00
0.00
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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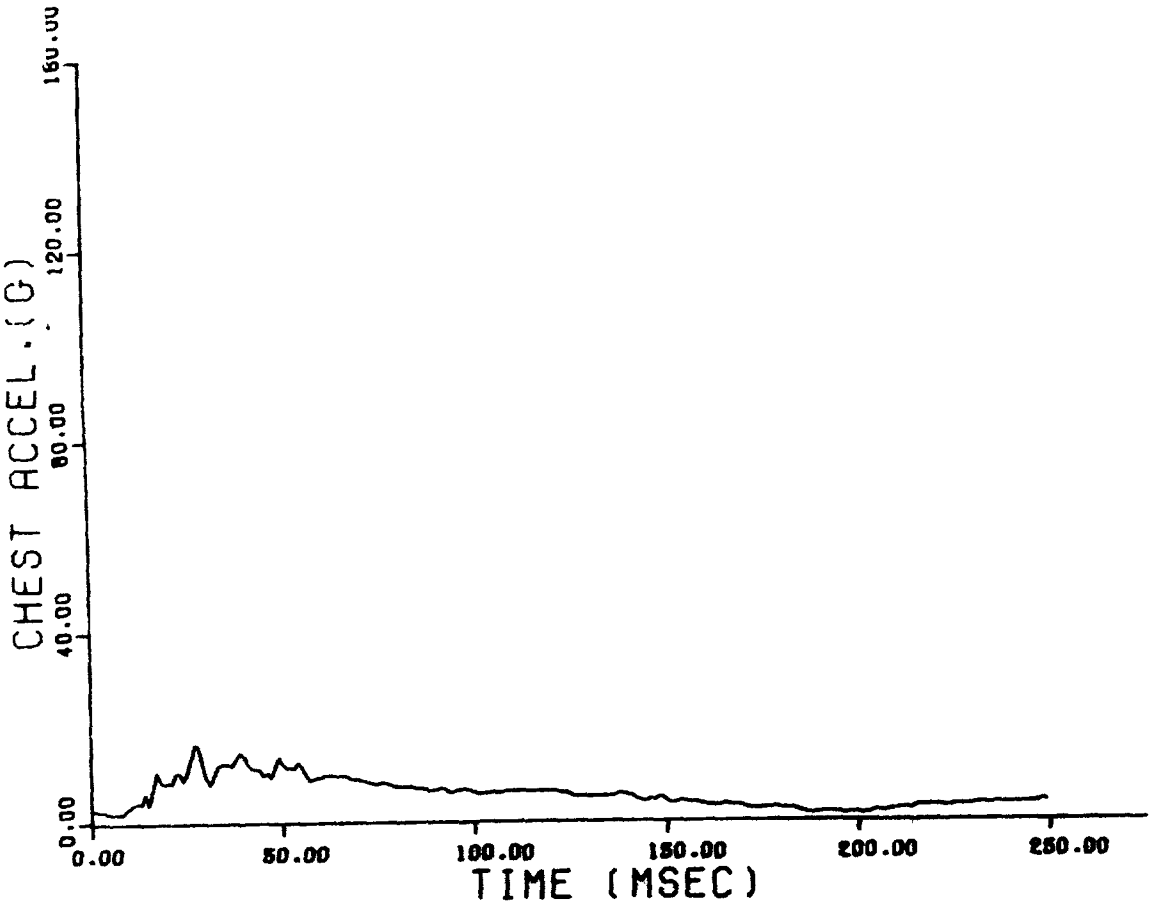
150.00
200.00
250.00
TIME (MSEC)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150.00
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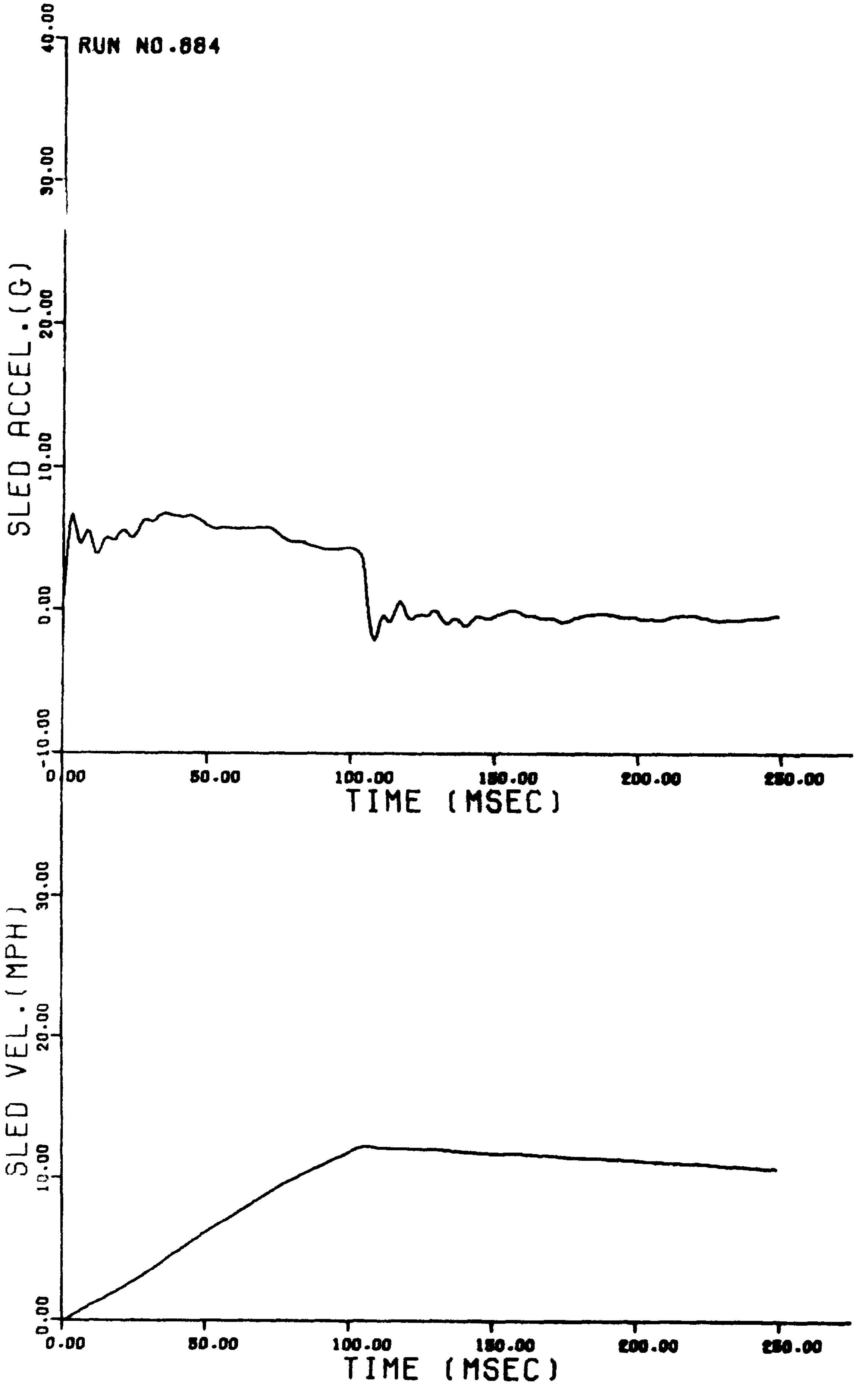
TIME (MSEC)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50.00
100.00
150.00
200.00
250.00
TIME (MSEC)
SLED VEL.(MPH)
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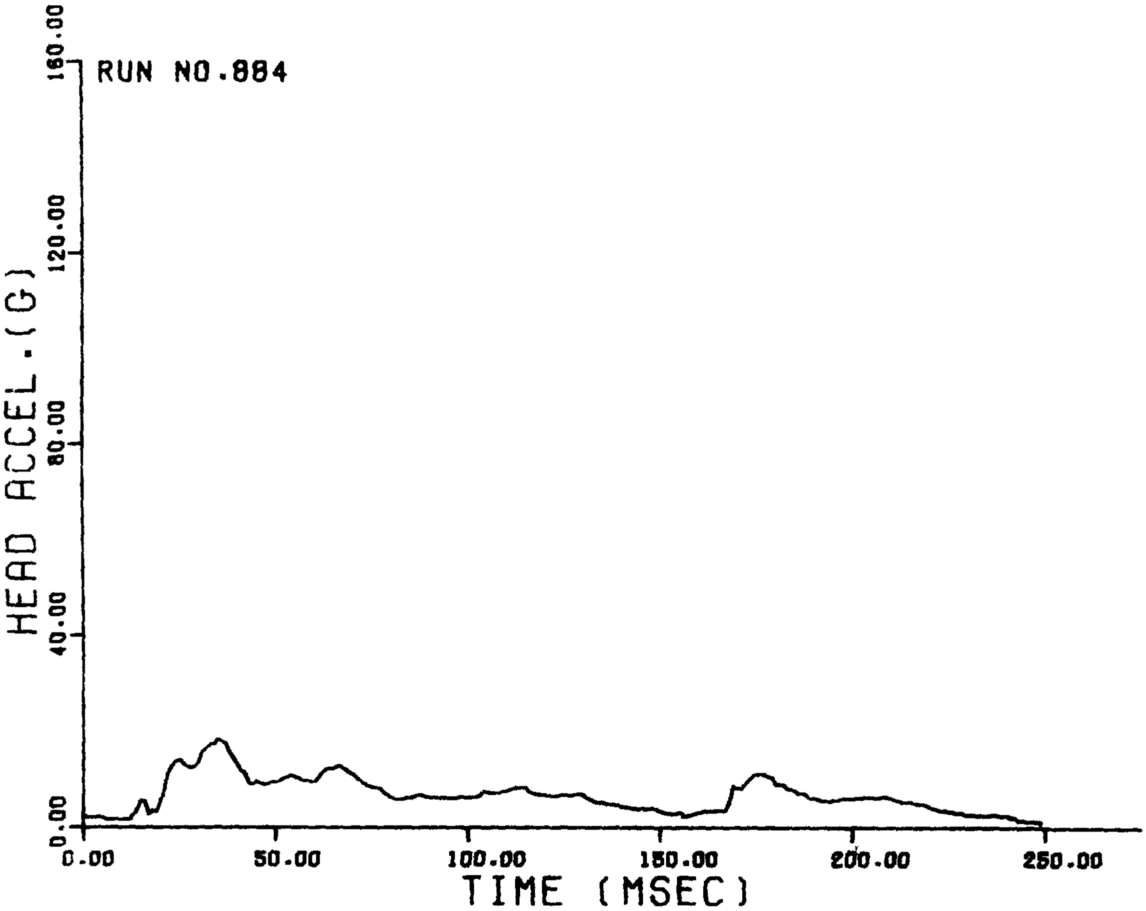
10.00
0.00
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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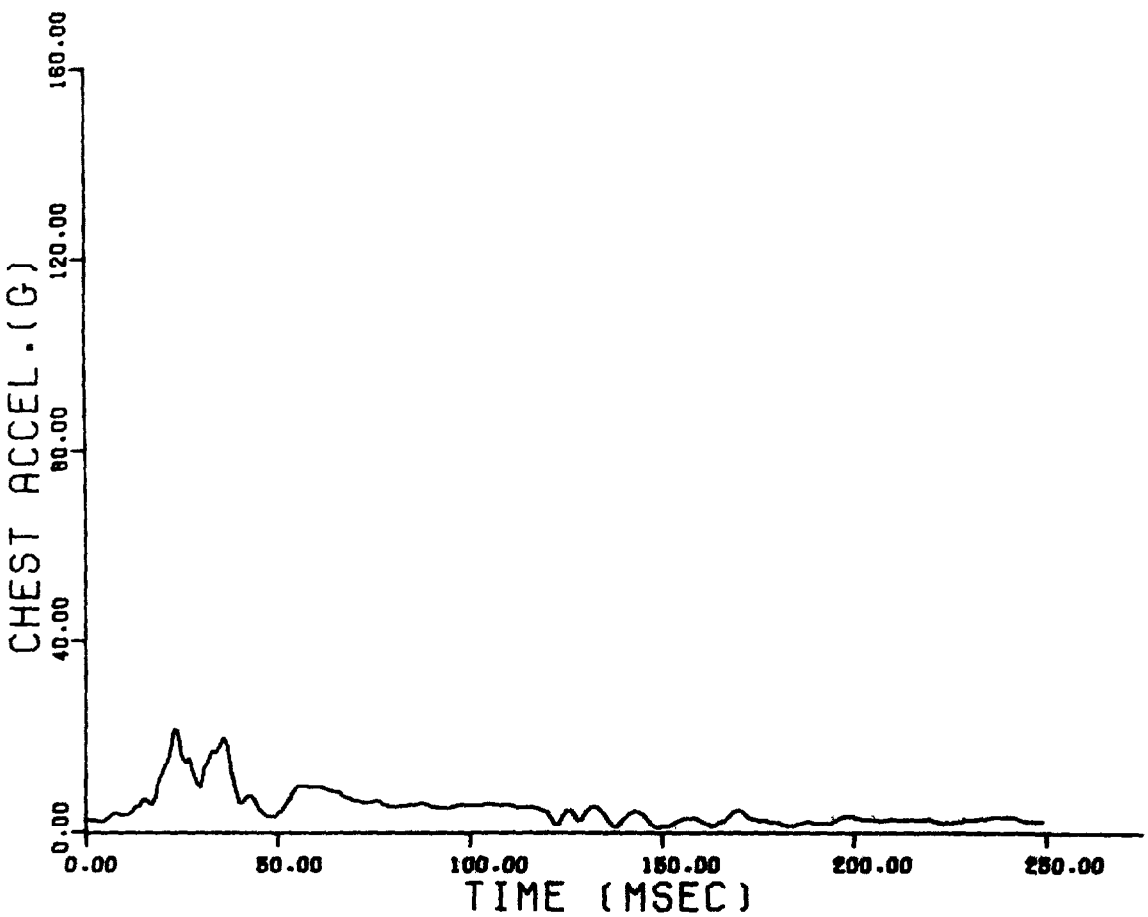
250.00
TIME (MSEC)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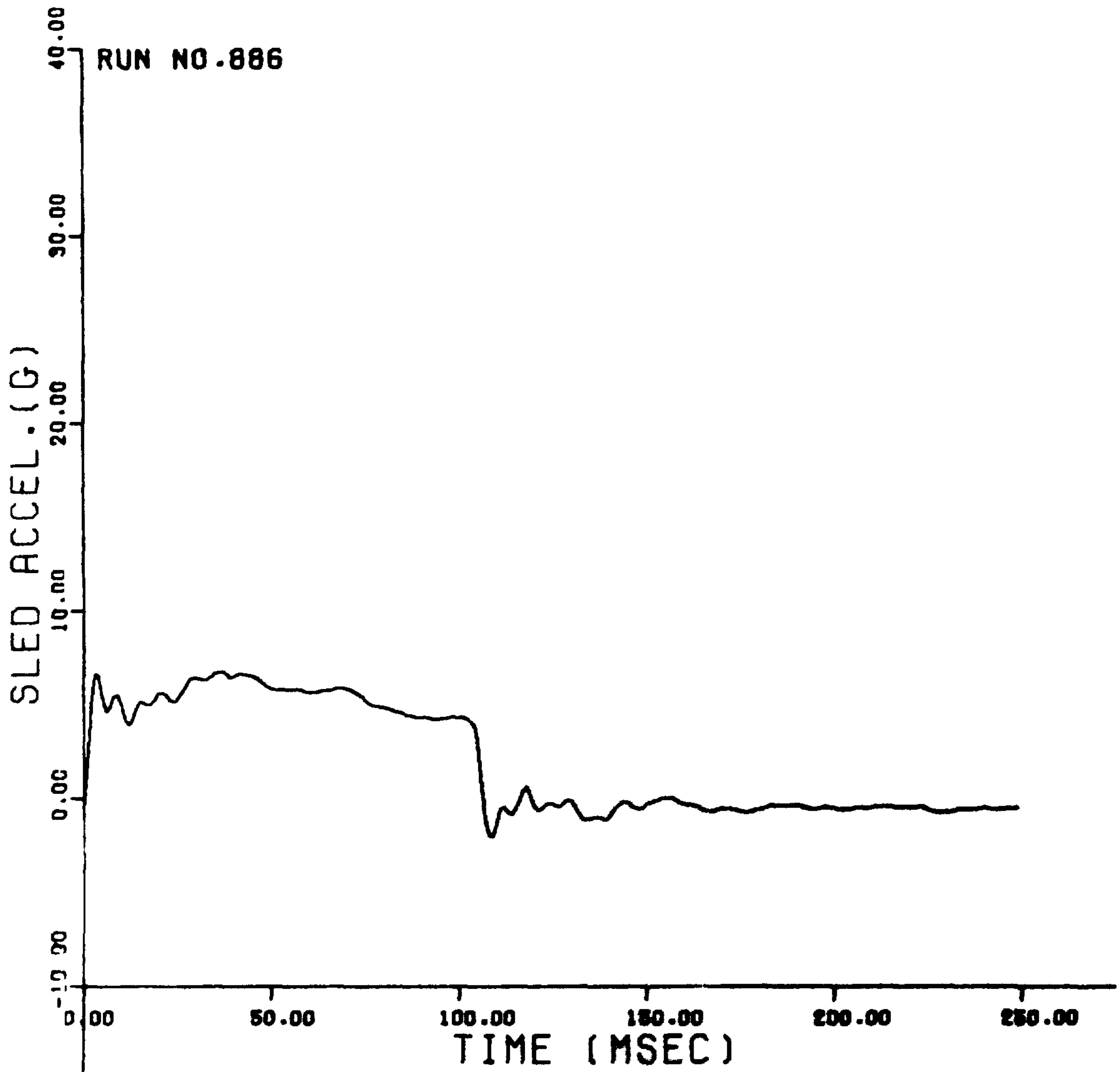
150.00
200.00
250.00
TIME (MSEC)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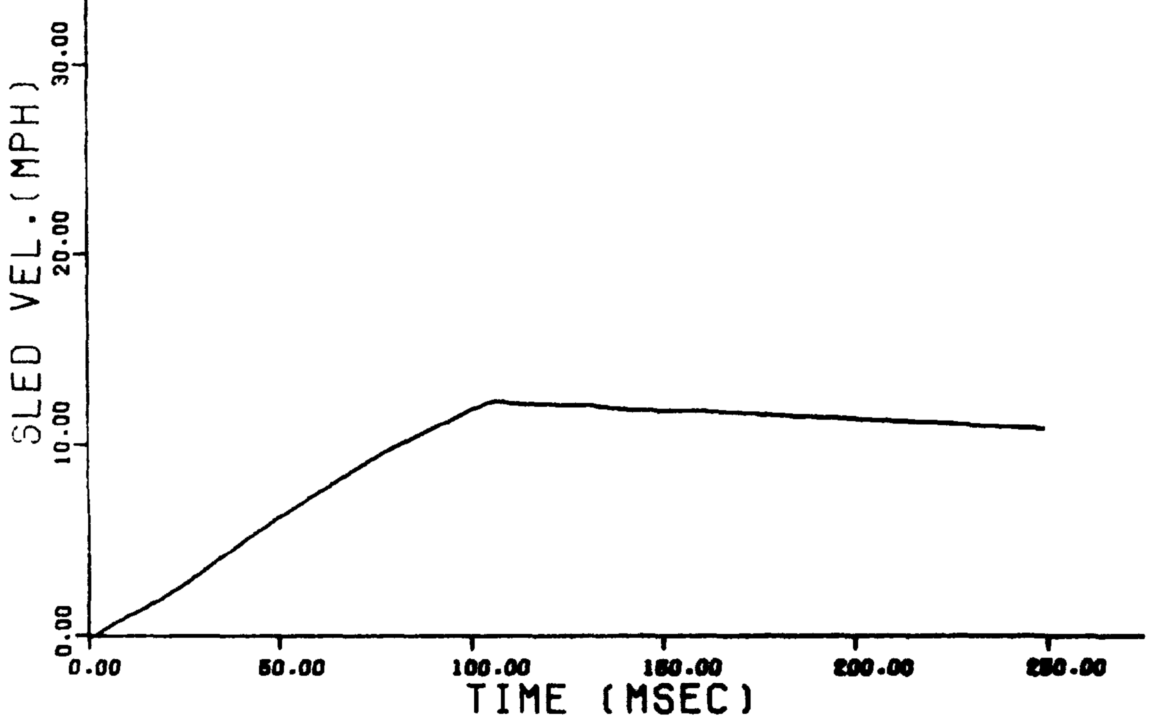
100.00
150.00
200.00
250.00
TIME (MSEC)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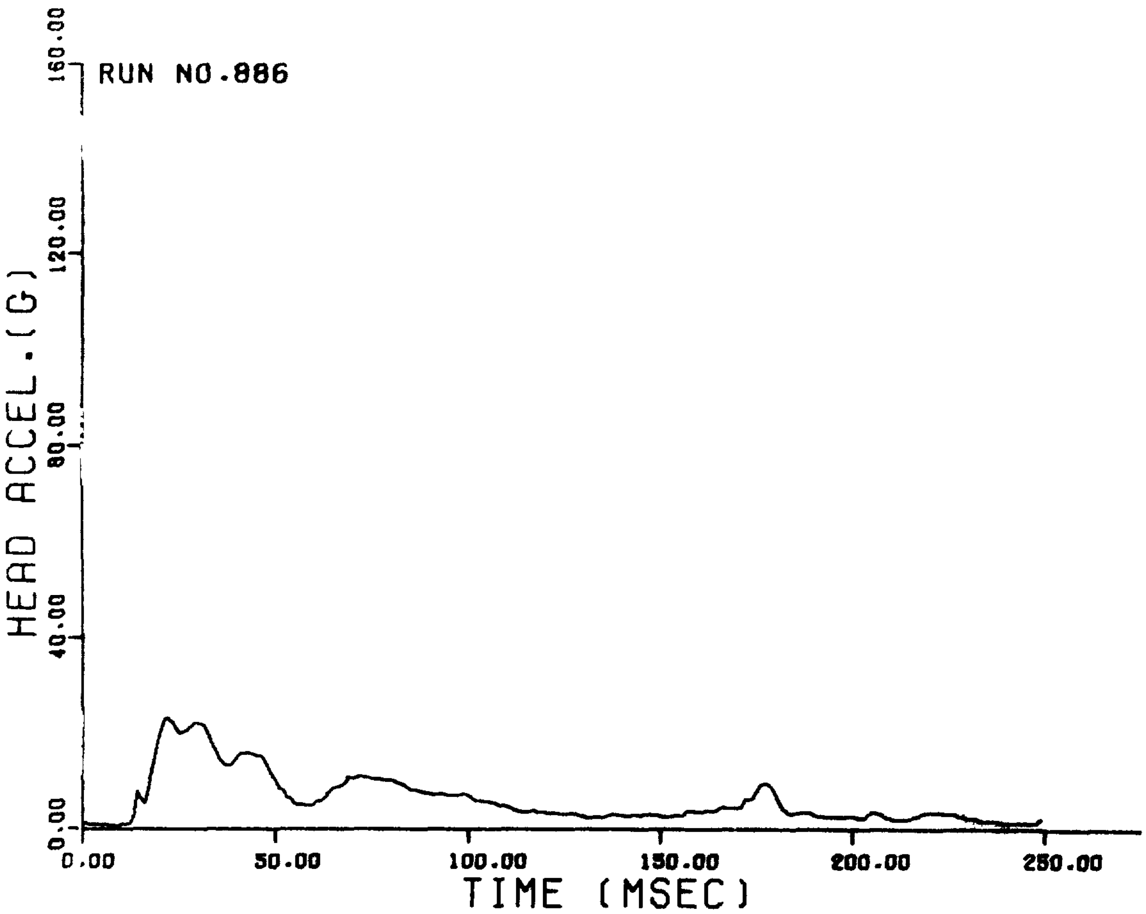
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)


RUN NO.886
HEAD ACCEL.(G)
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50.00
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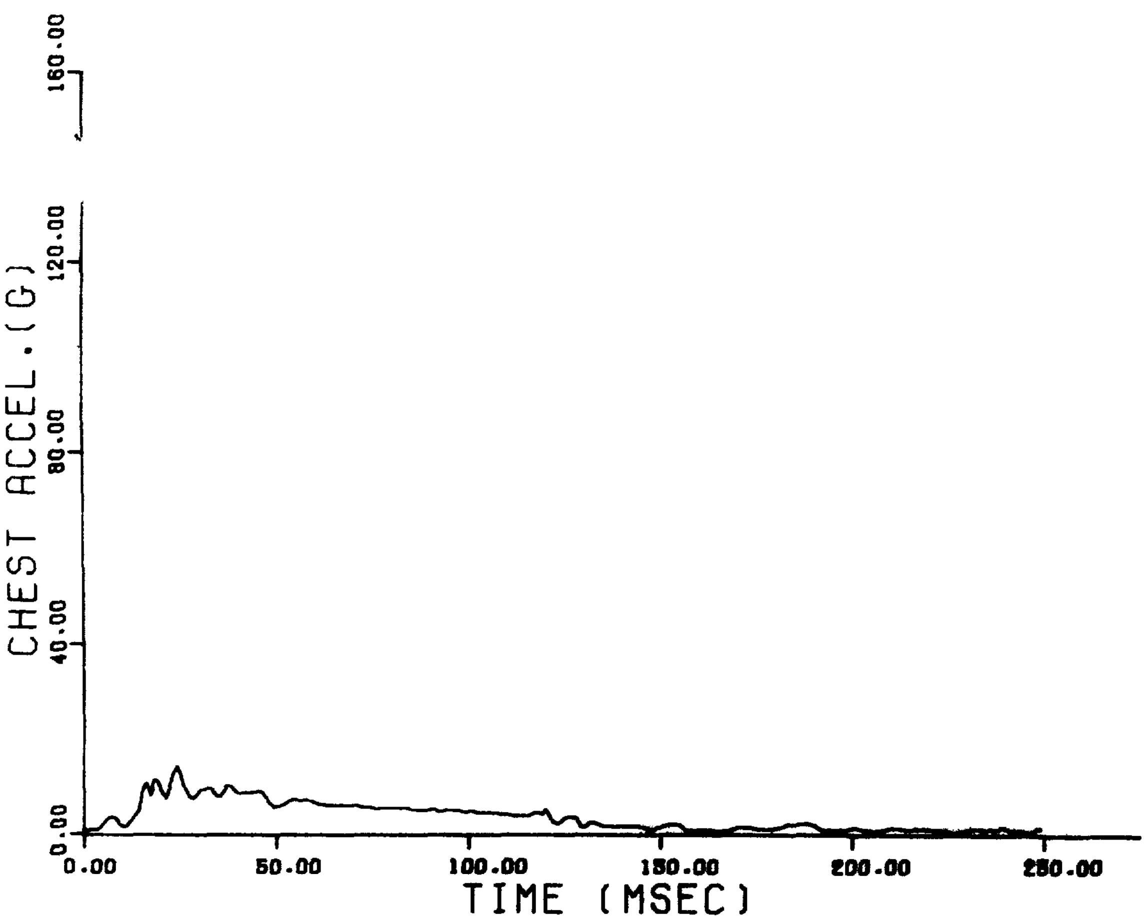
250.00
TIME (MSEC)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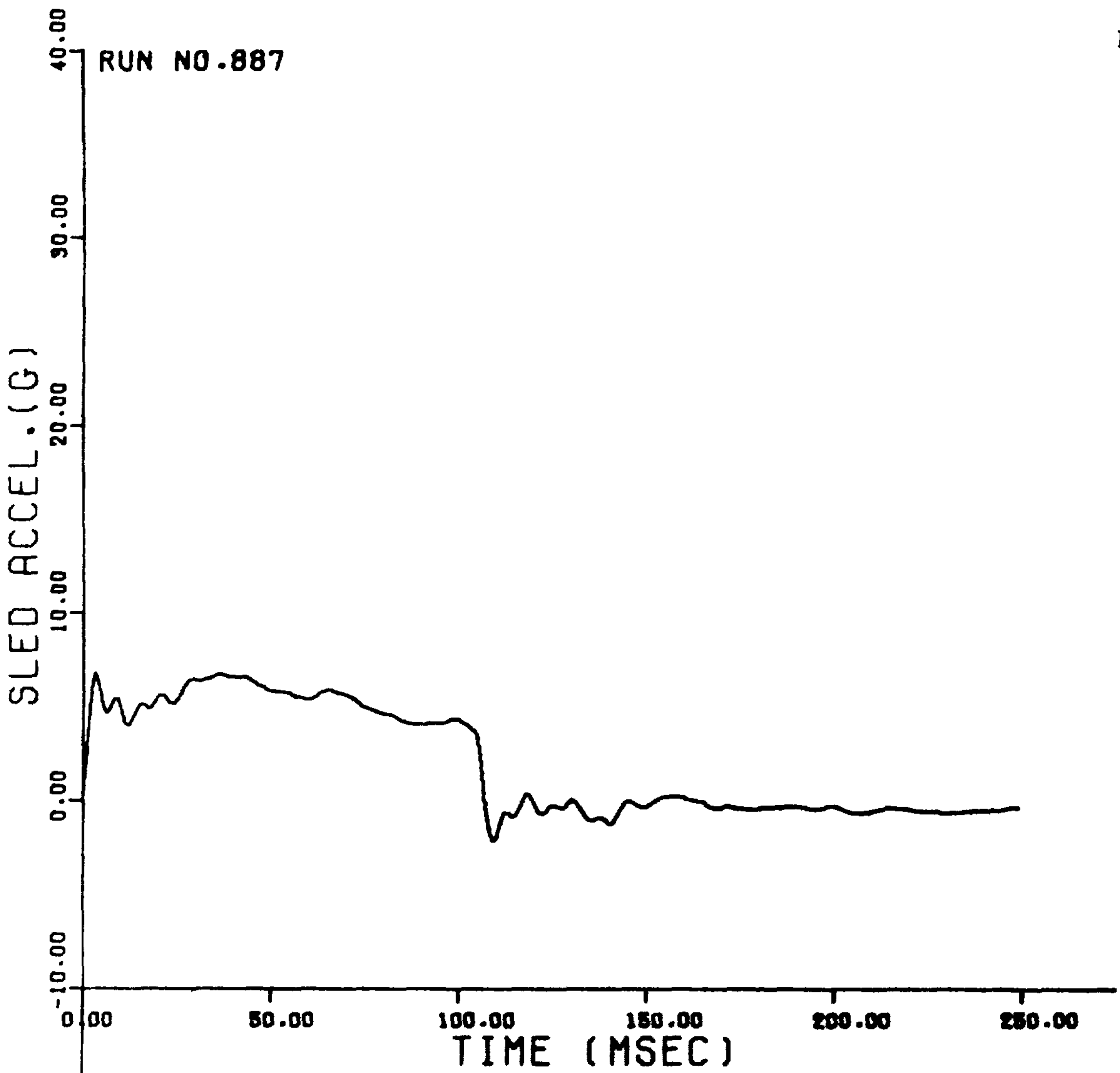
100.00
150.00
200.00
250.00
TIME (MSEC)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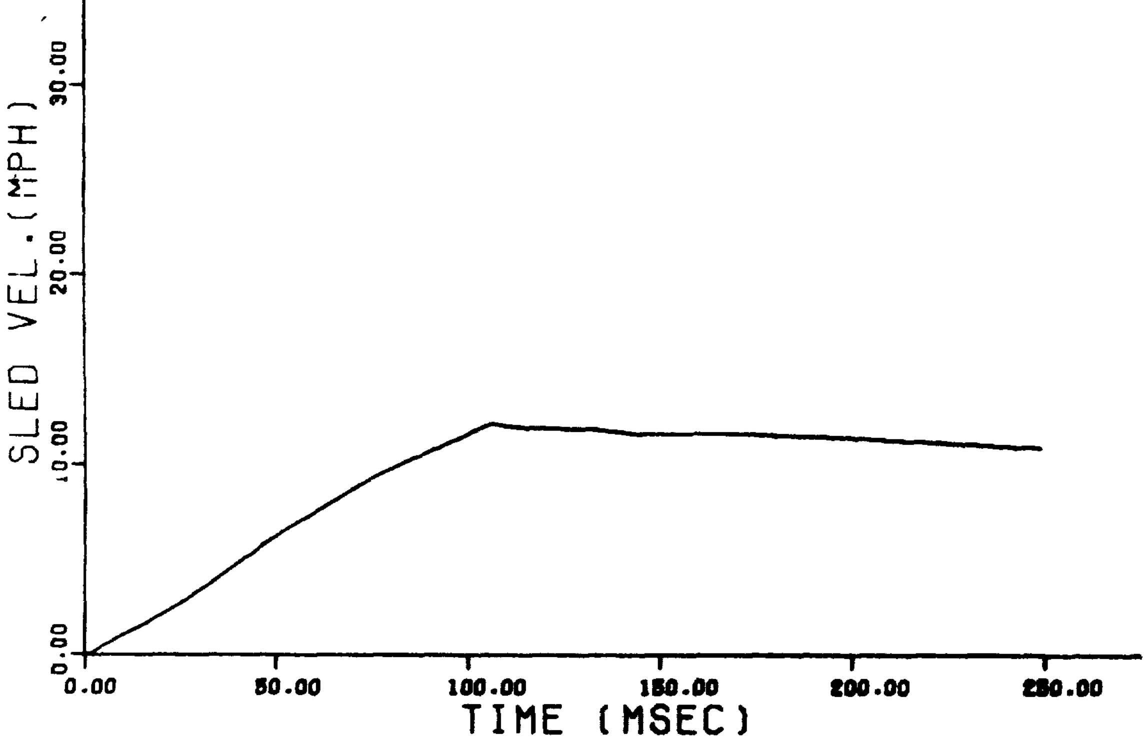
150.00
200.00
250.00
TIME (MSEC)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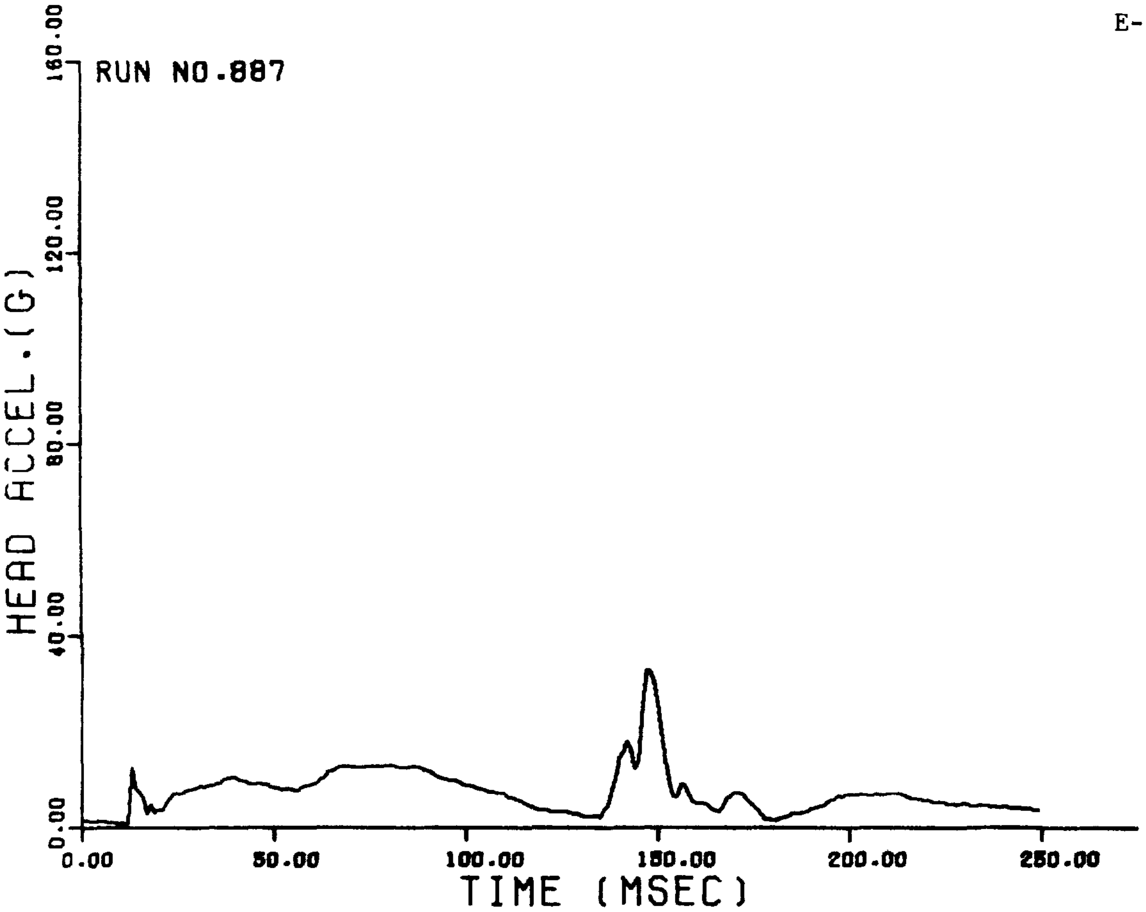
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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120.00
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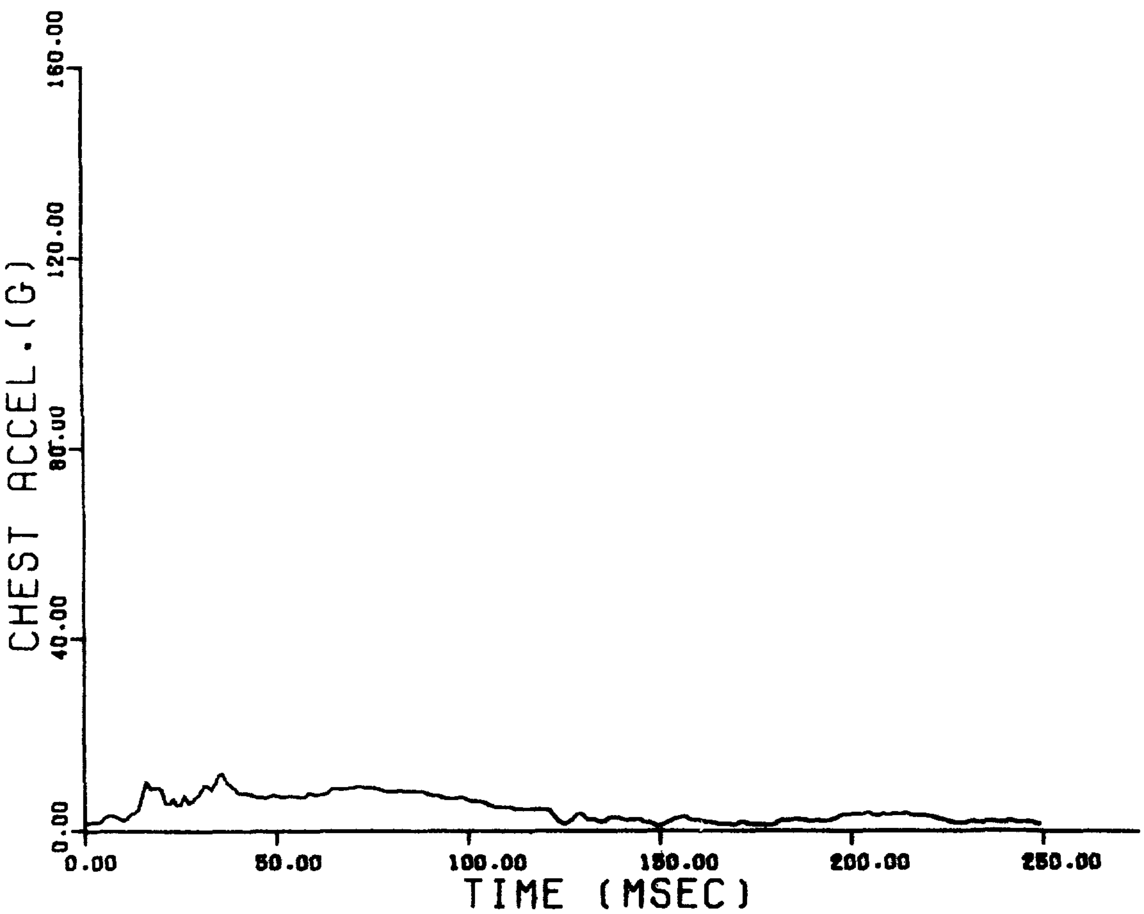
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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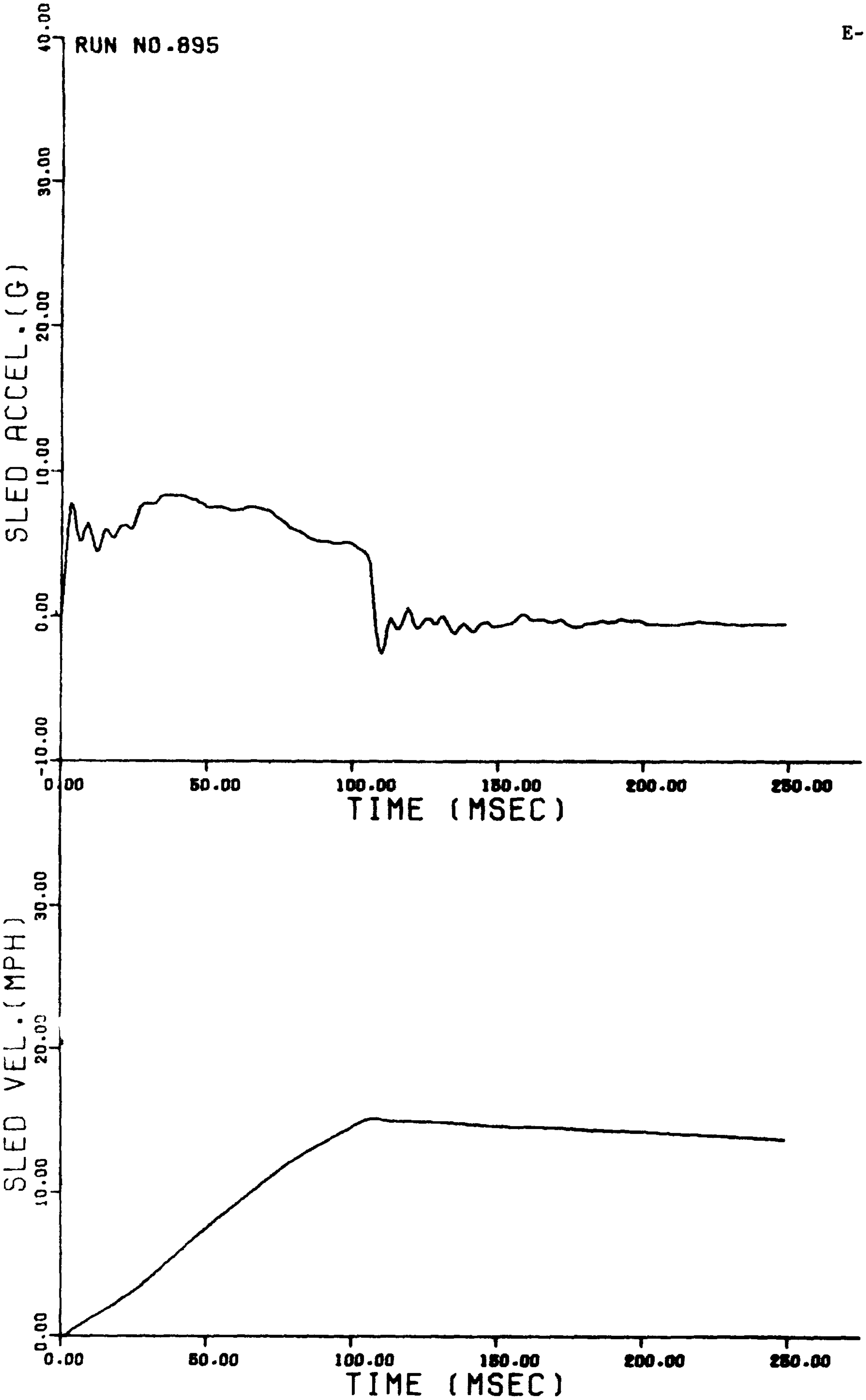
120.00
160.00
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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0.00
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0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)
SLED VEL.(MPH)
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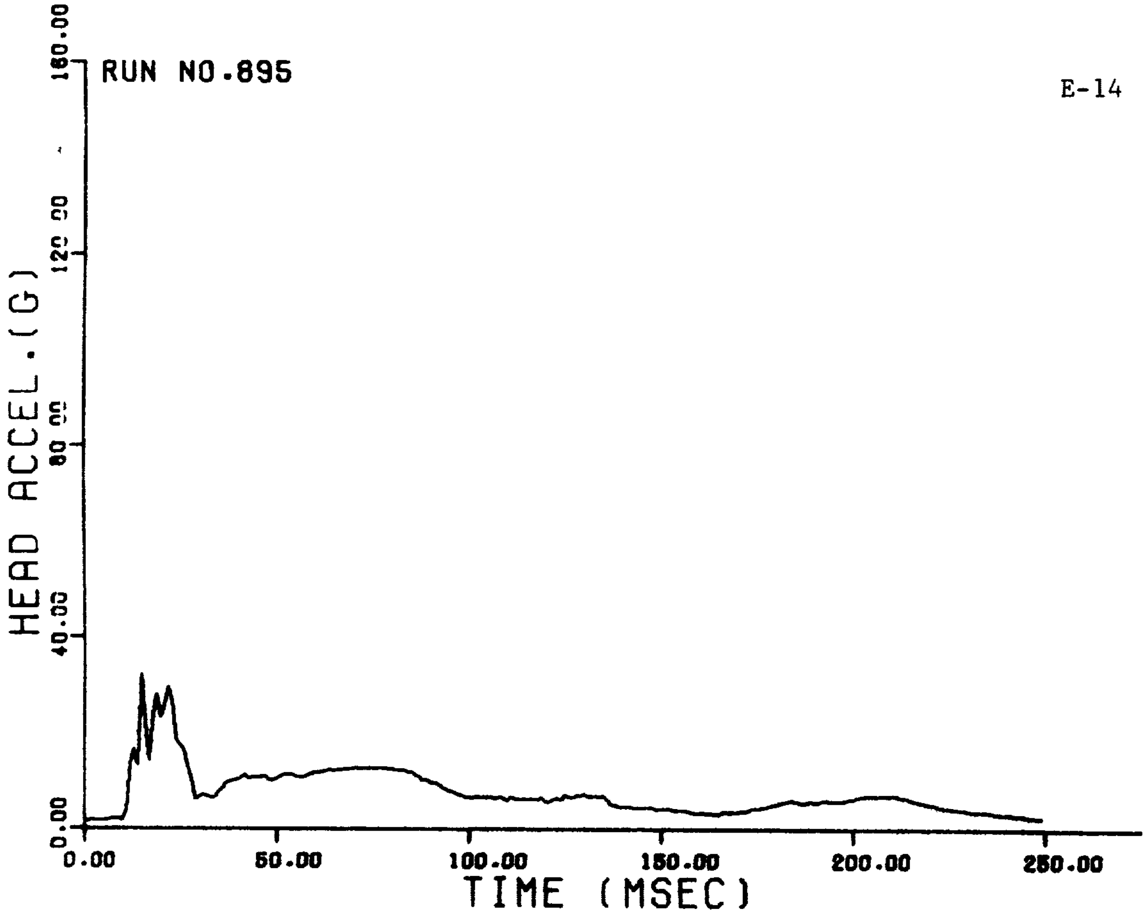
10.00
0.00
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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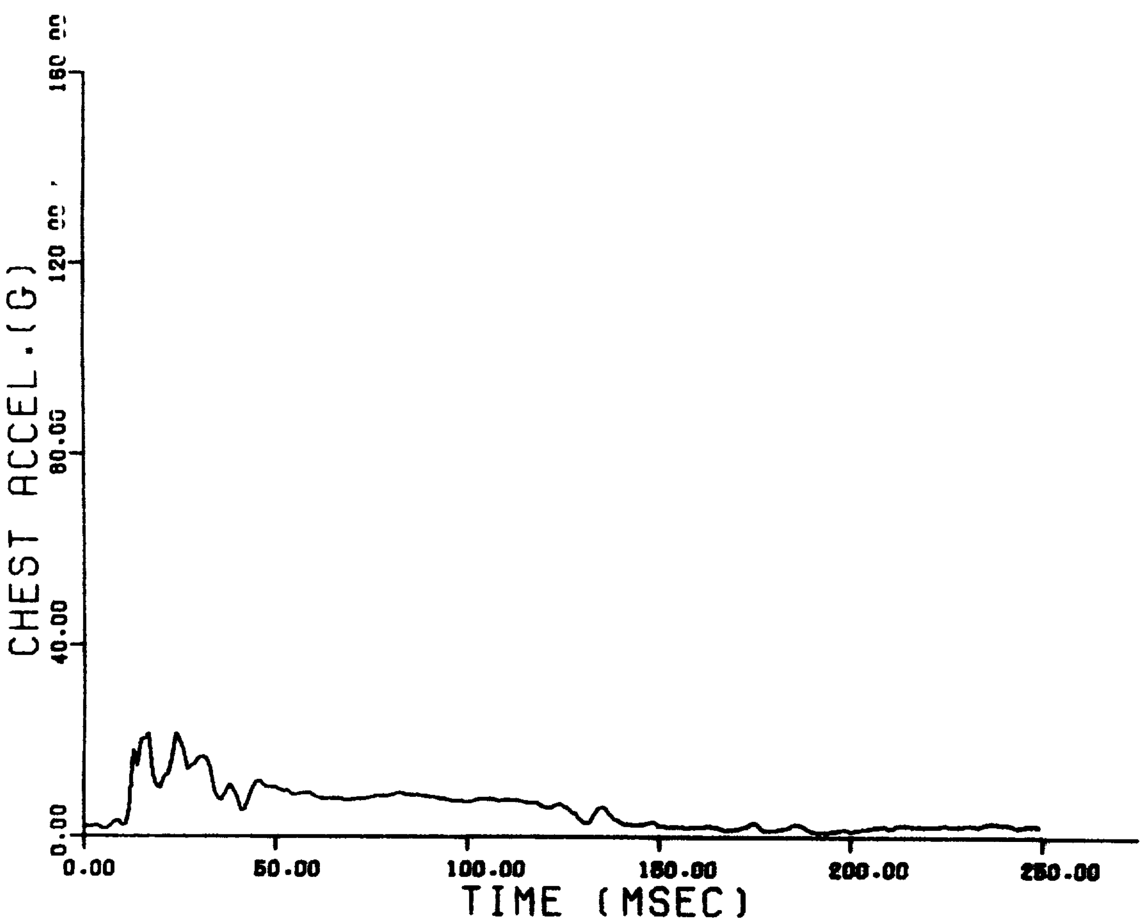
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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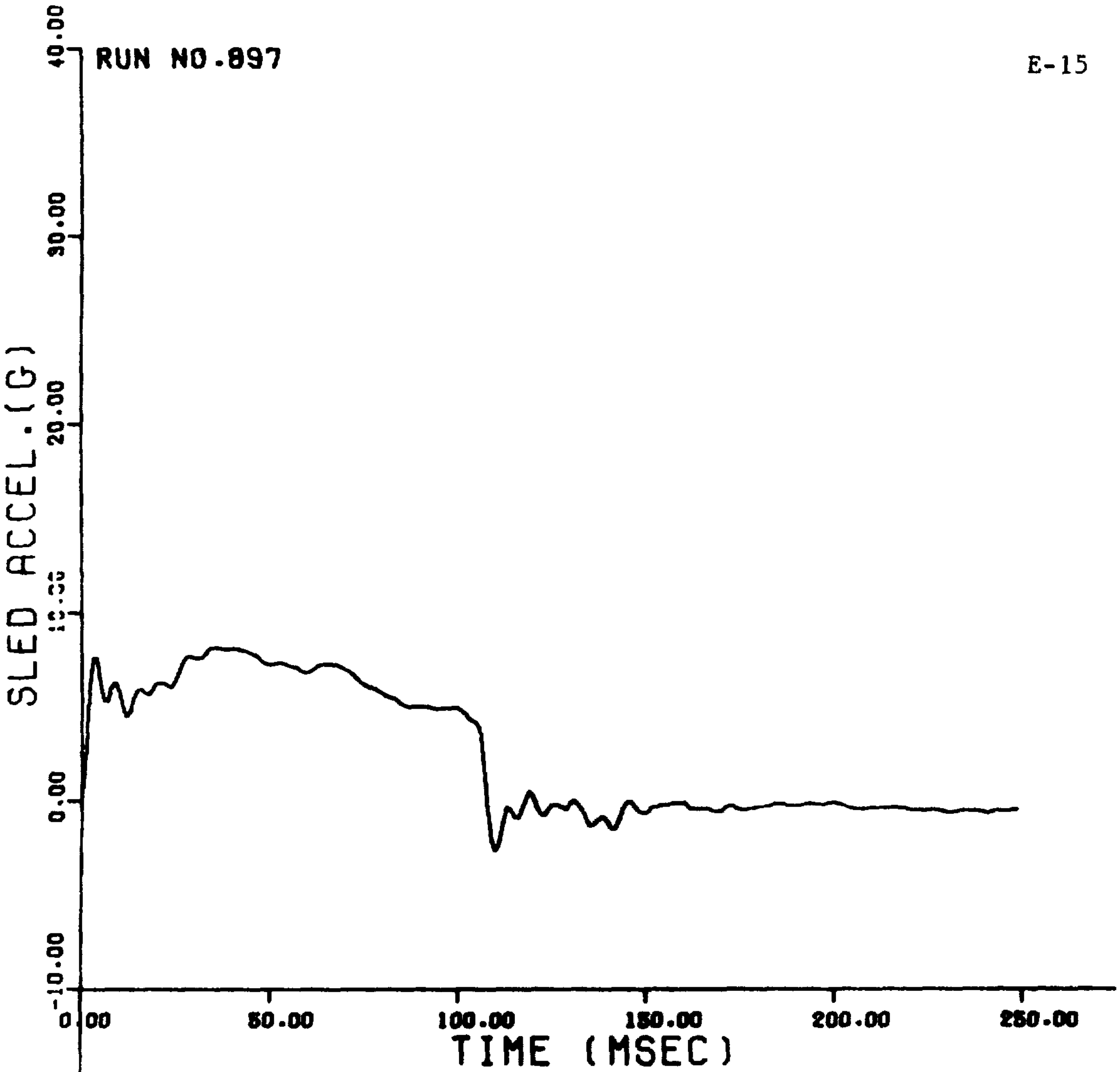
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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50.00
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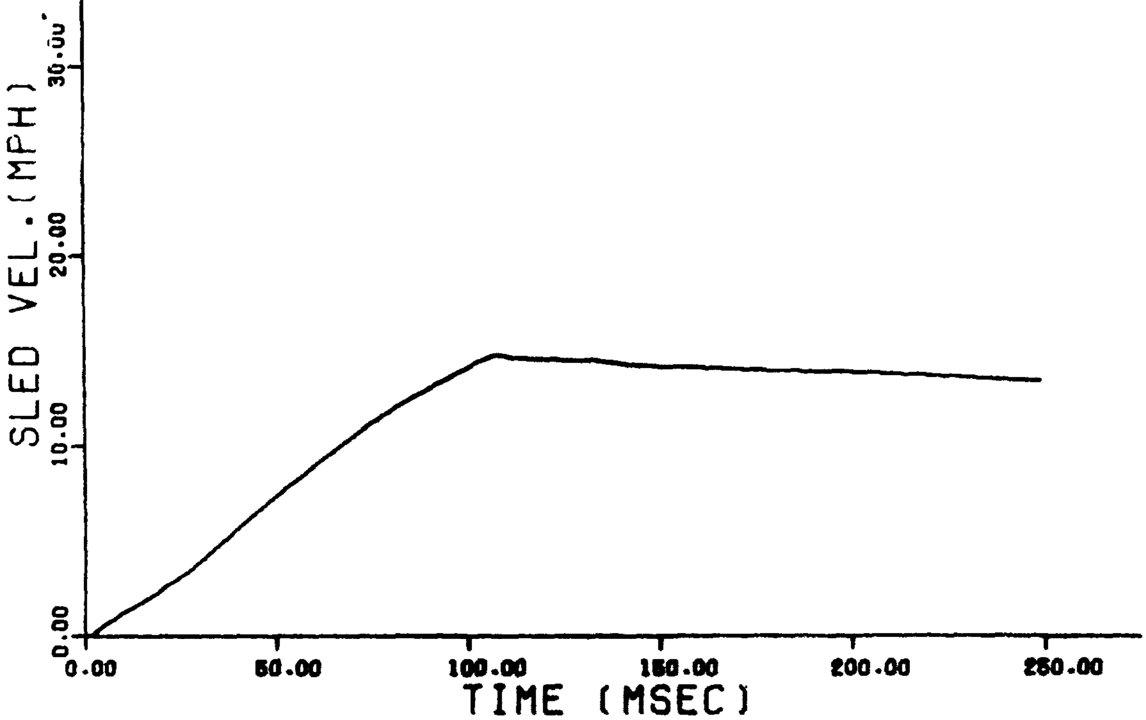
150.00
200.00
250.00
TIME (MSEC)


SLED VEL.(MPH)
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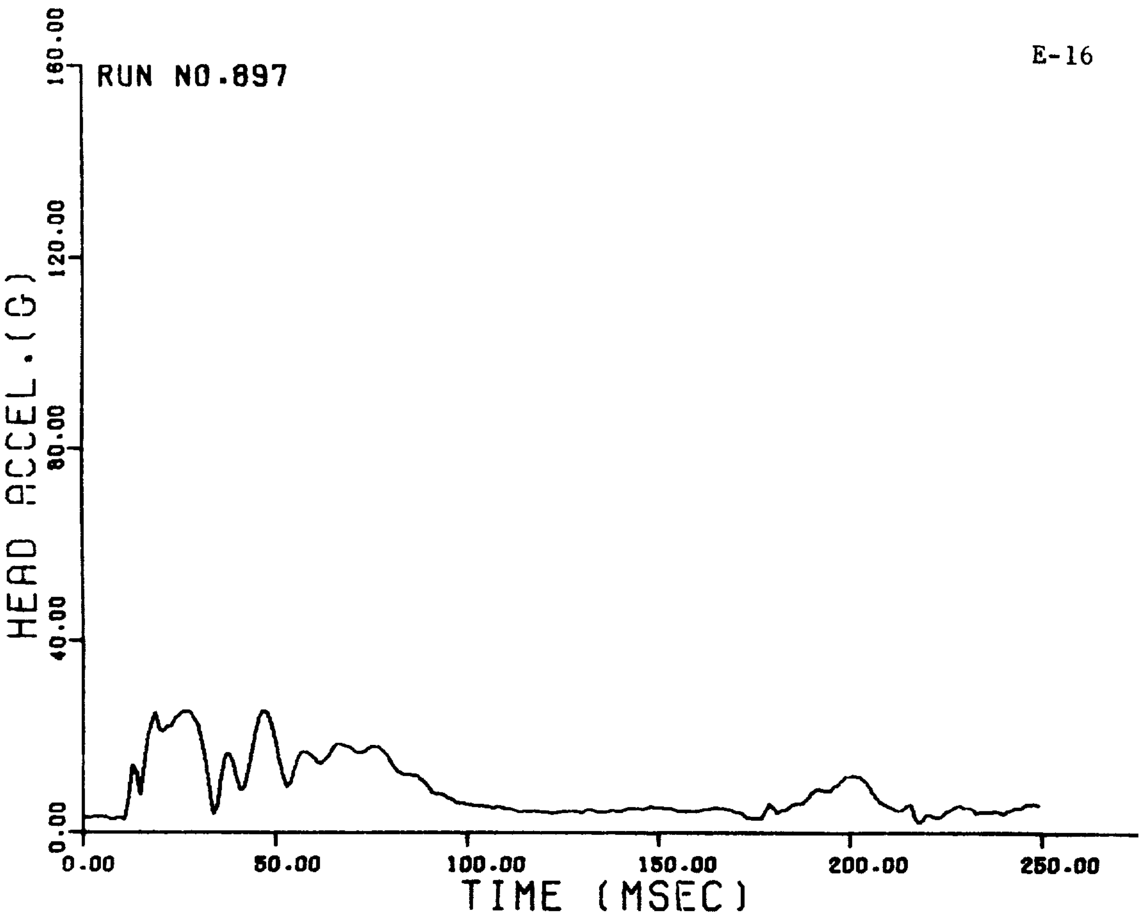
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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TIME (MSEC)
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120.00
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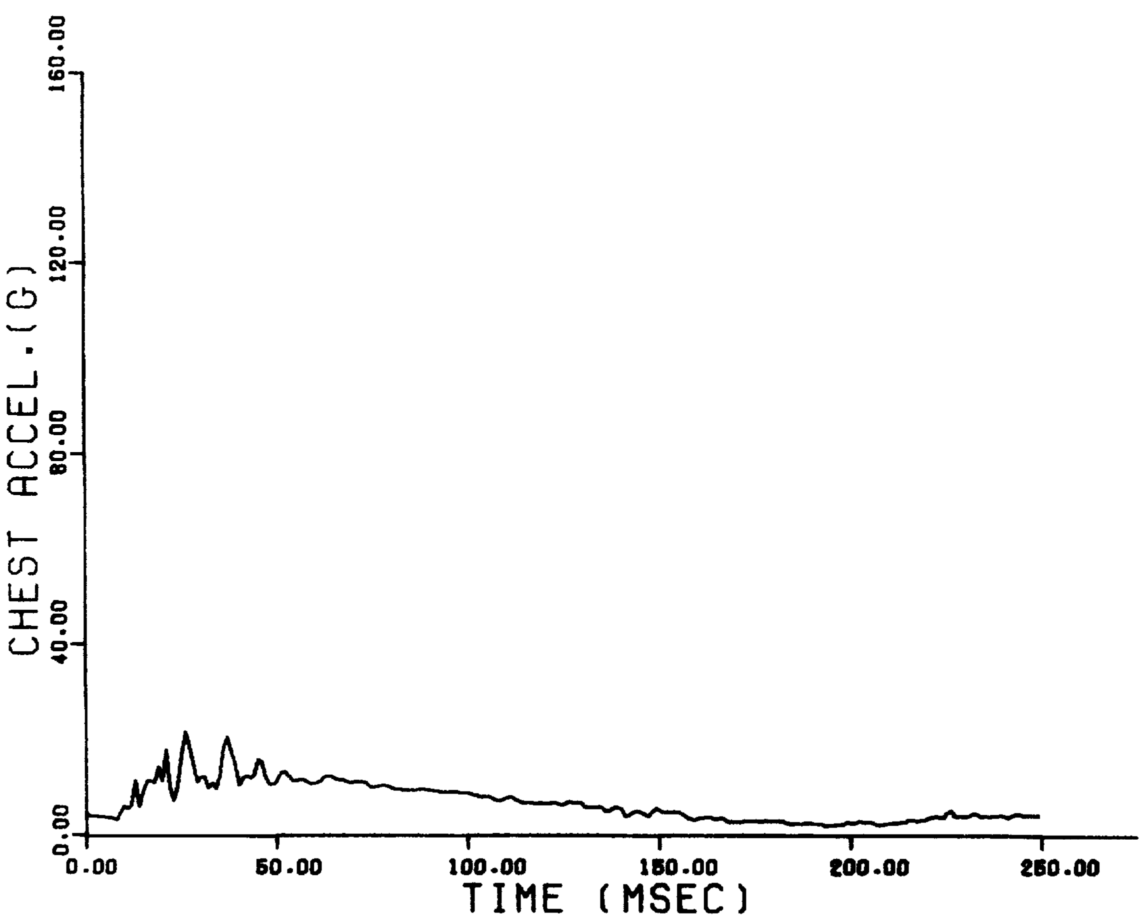
50.00
100.00
150.00
200.00
250.00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TIME (MSEC)
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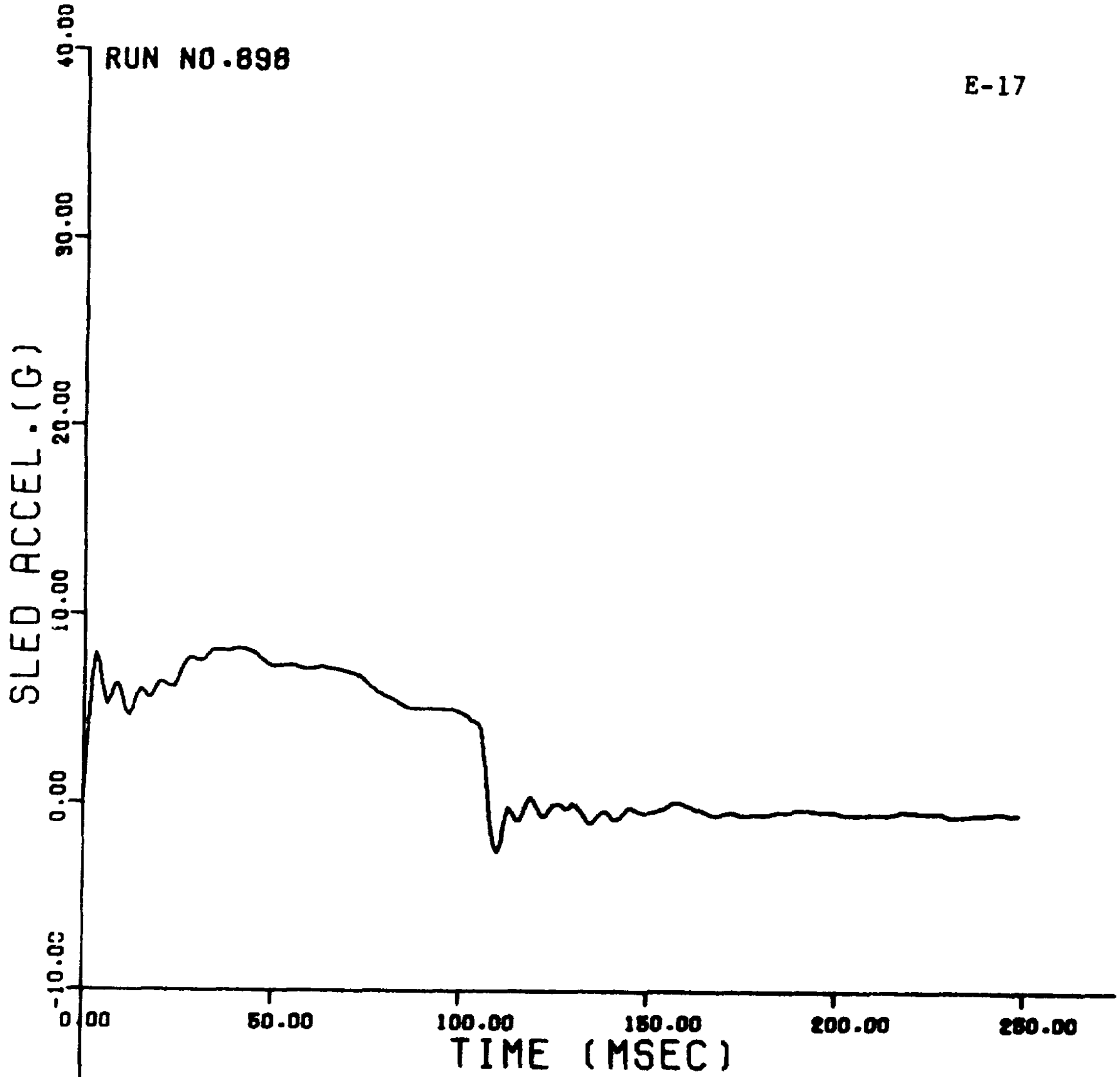
120.00
160.00
50.00
100.00
150.00
200.00
250.00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-10.00
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50.00
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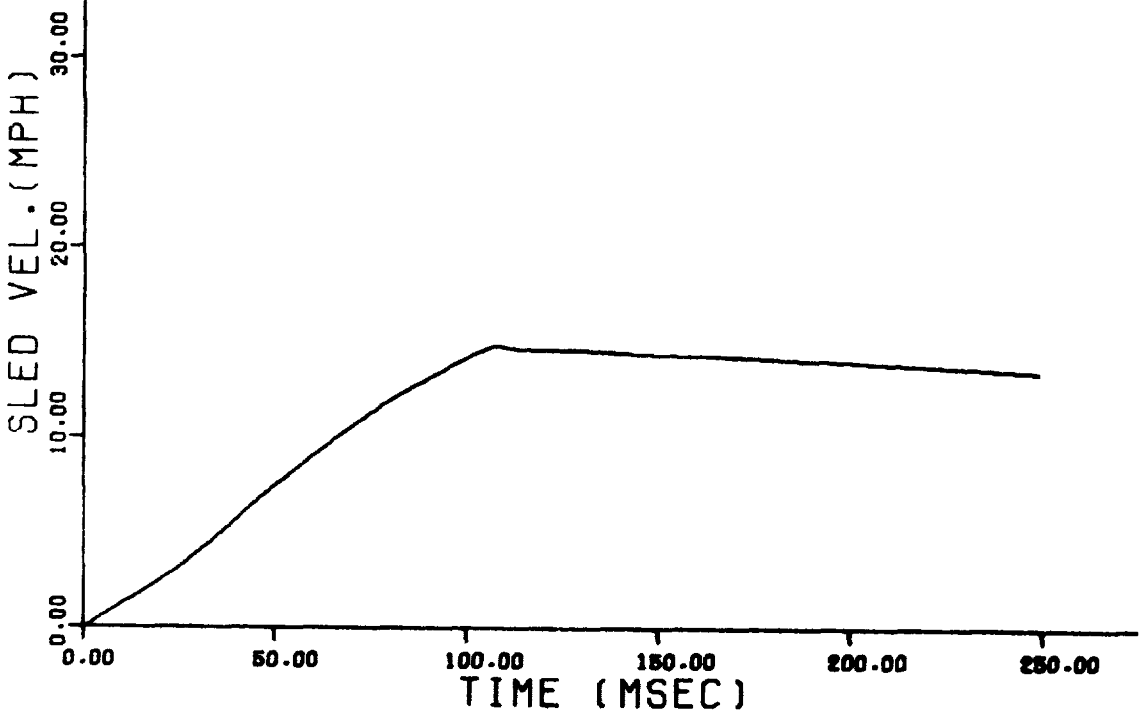
150.00
200.00
250.00
TIME (MSEC)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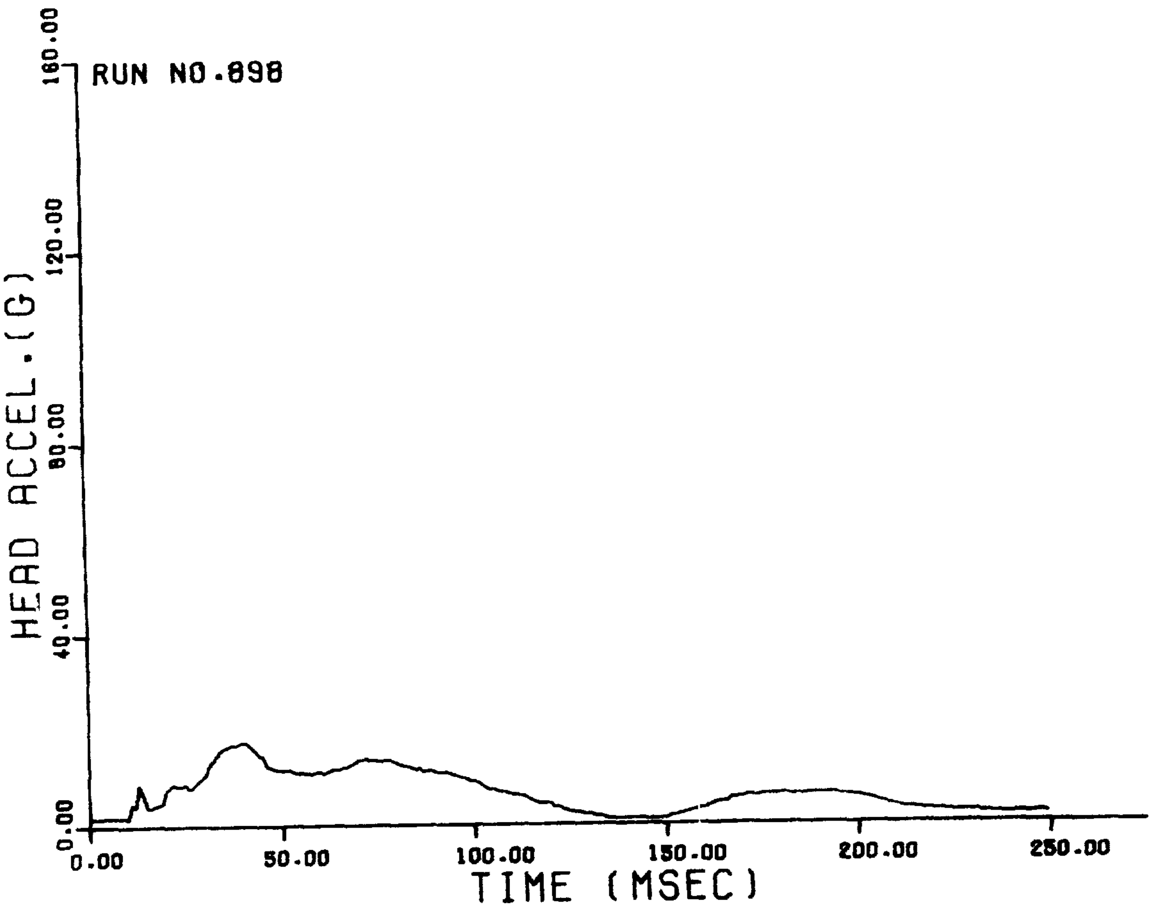
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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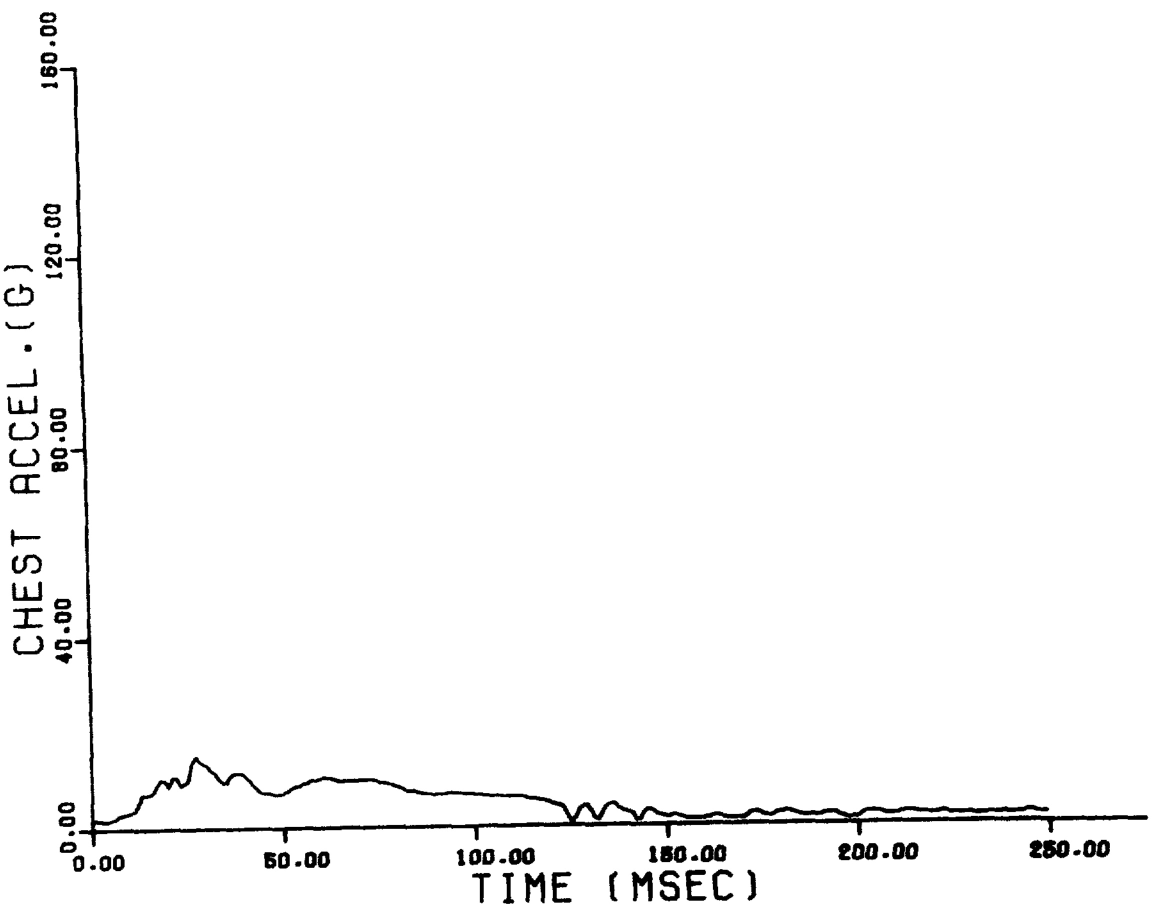
50.00
100.00
150.00
200.00
250.00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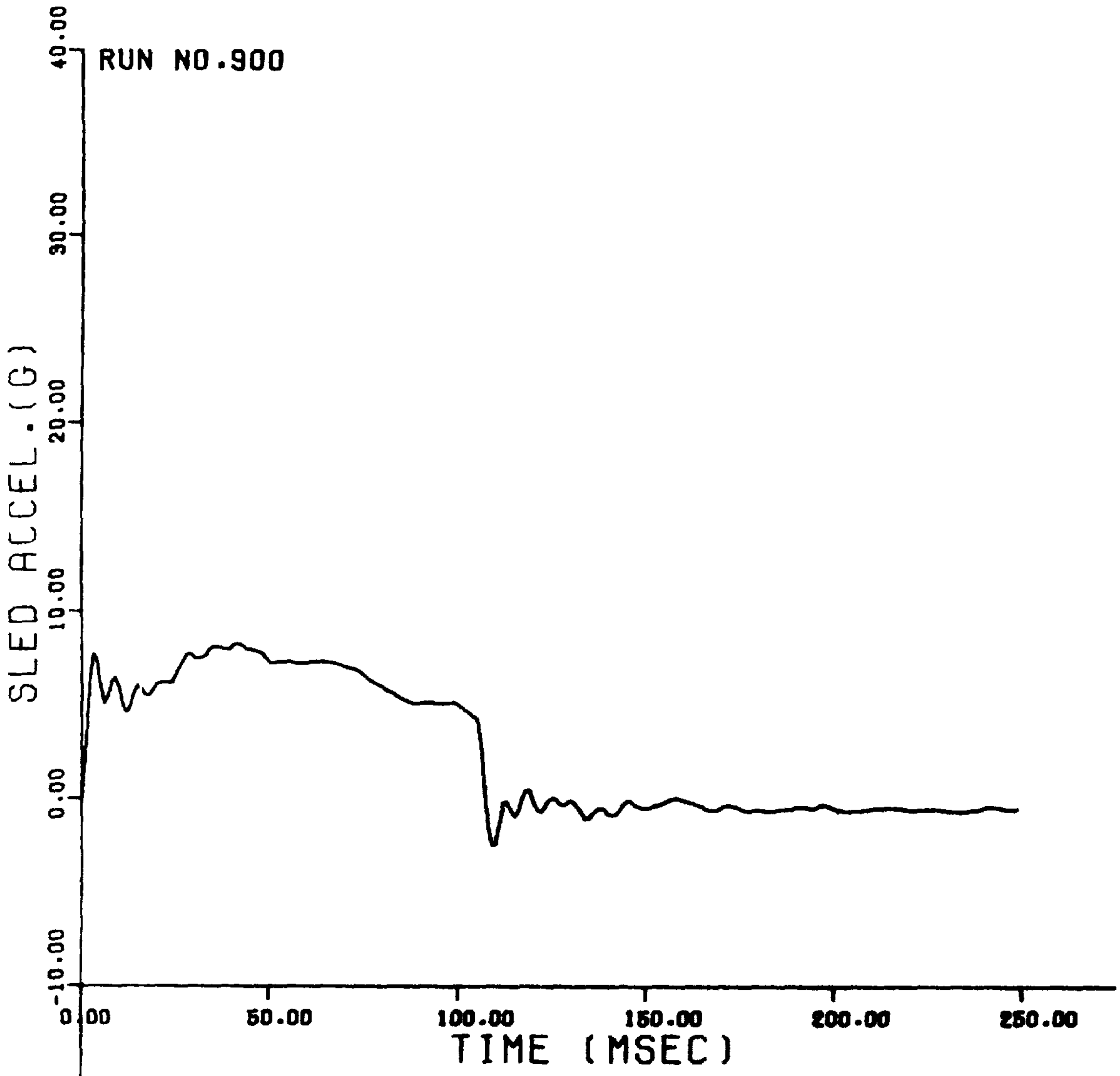
200.00
250.00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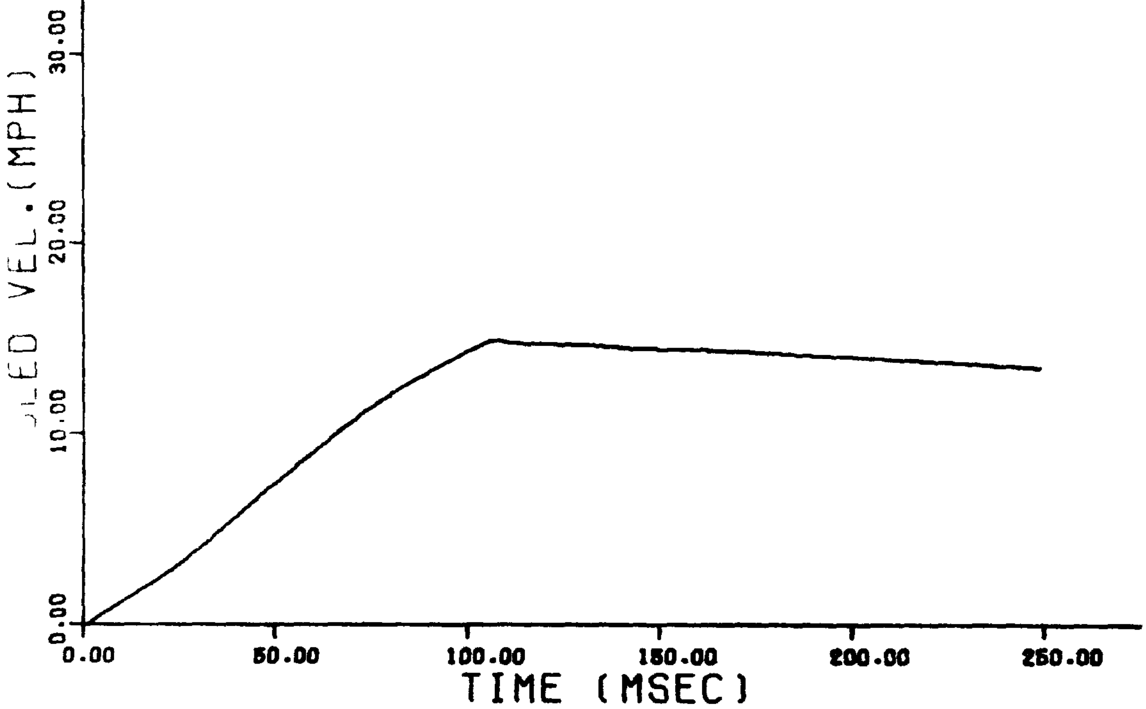
250.00
TIME (MSEC)


SLED VEL.(MPH)
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10.00
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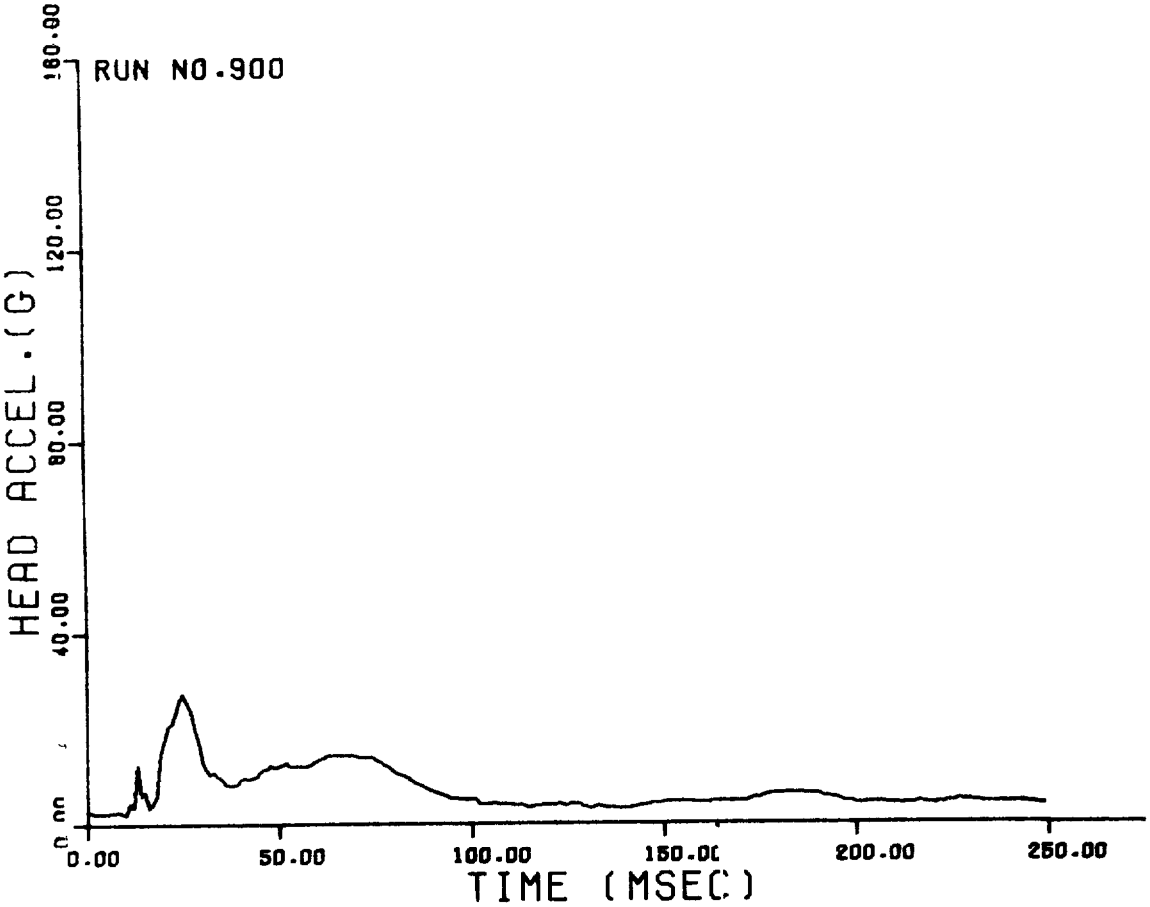
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)



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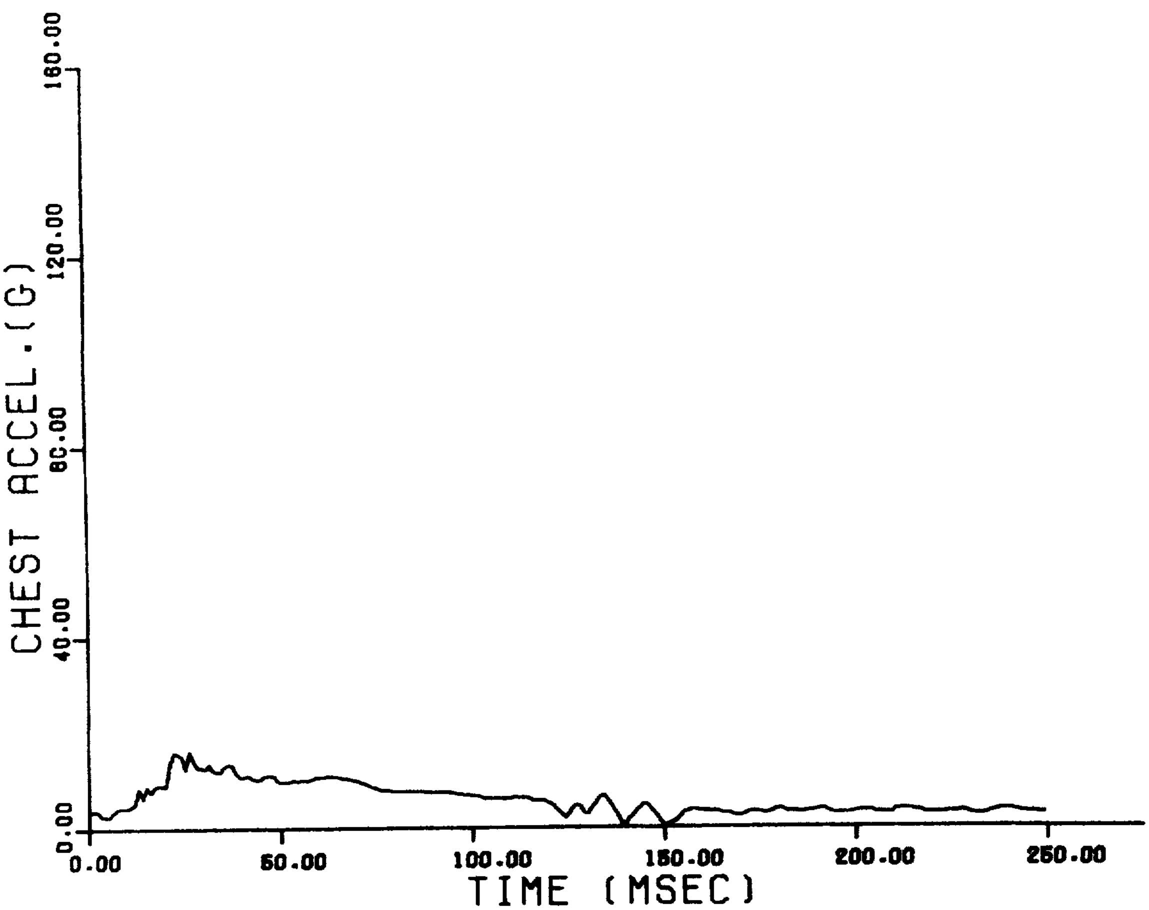
250.00



CHEST ACCEL.(G)
TIME (MSEC)
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120.00
160.00
0.00
50.00
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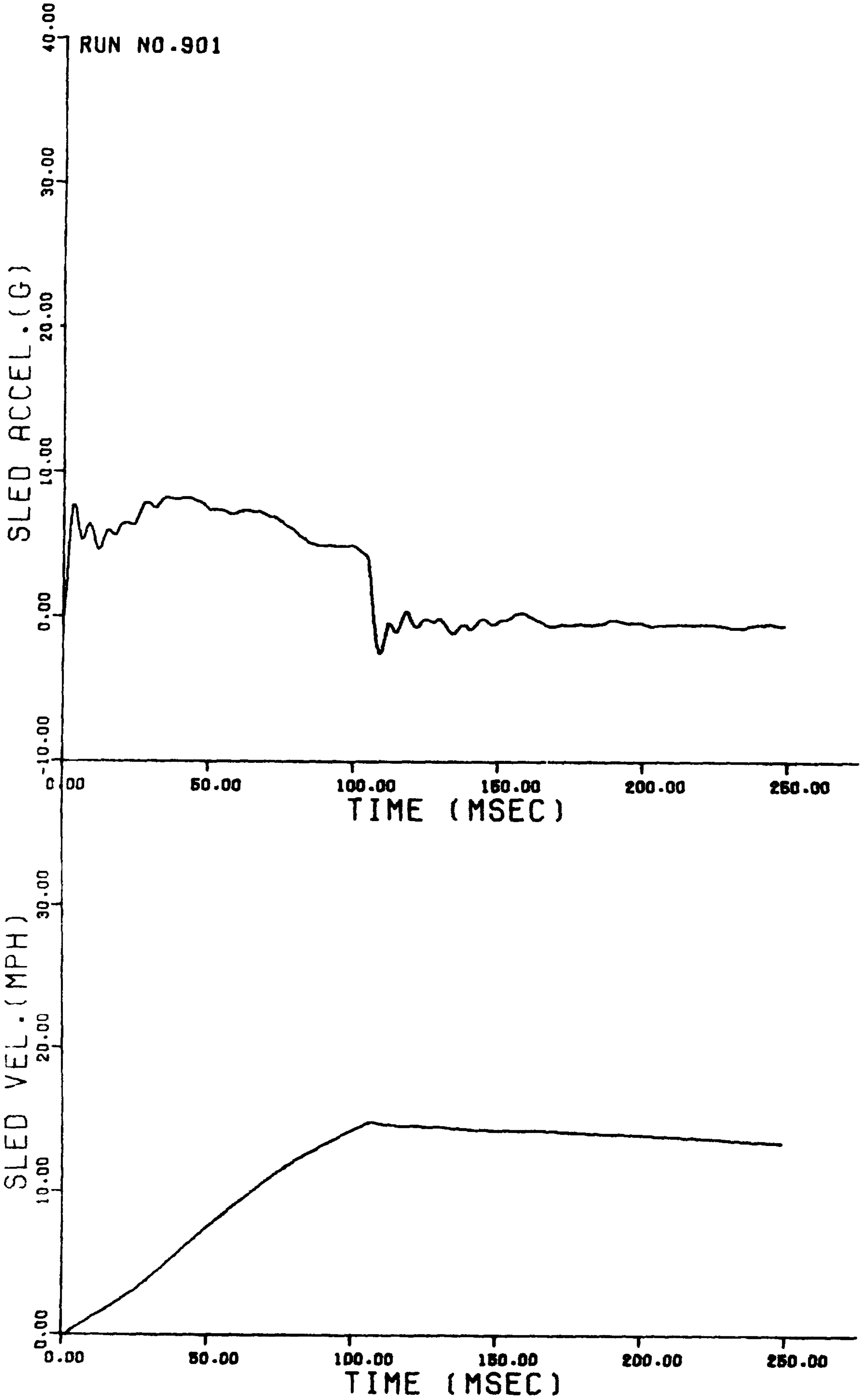
150.00
200.00
250.00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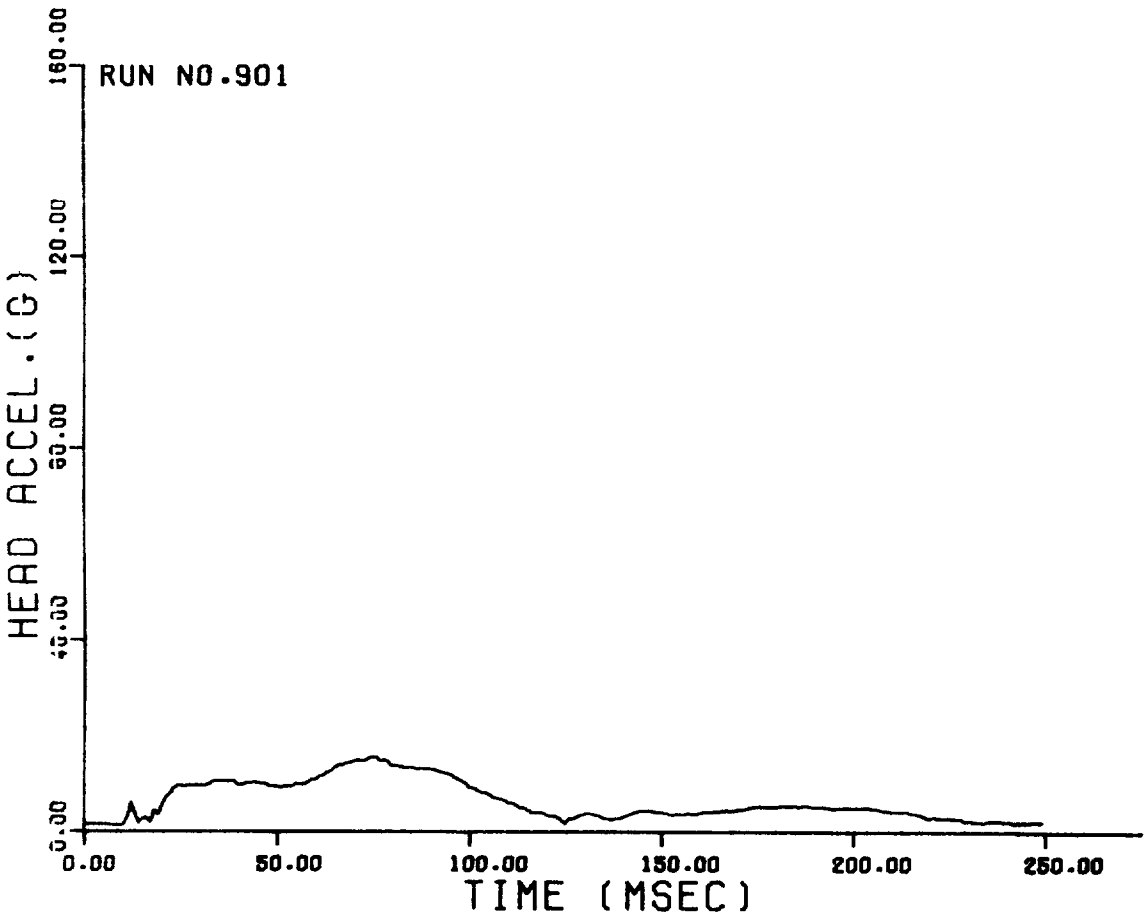
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)
SLED VEL.(MPH)
30.00
20.00
10.00
0.00
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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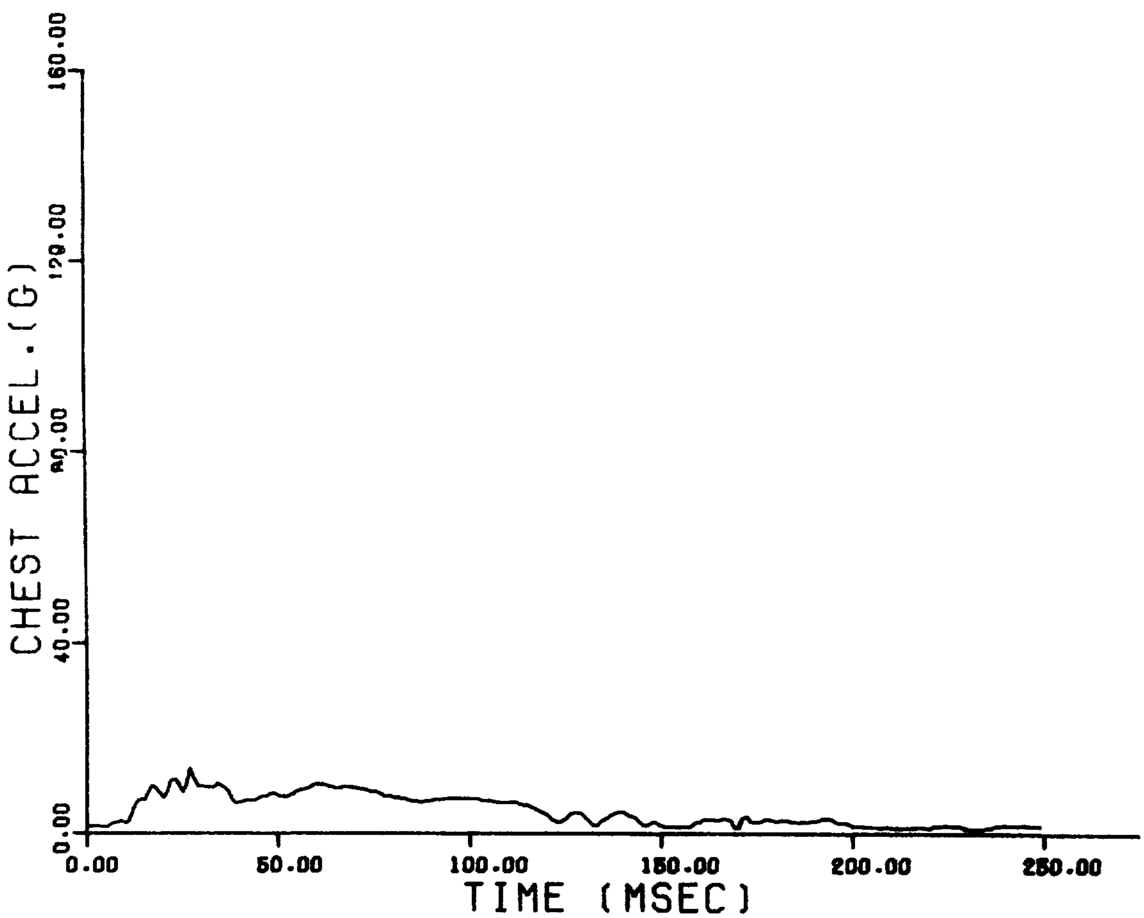
100.00
150.00
200.00
250.00
TIME (MSEC)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150.00
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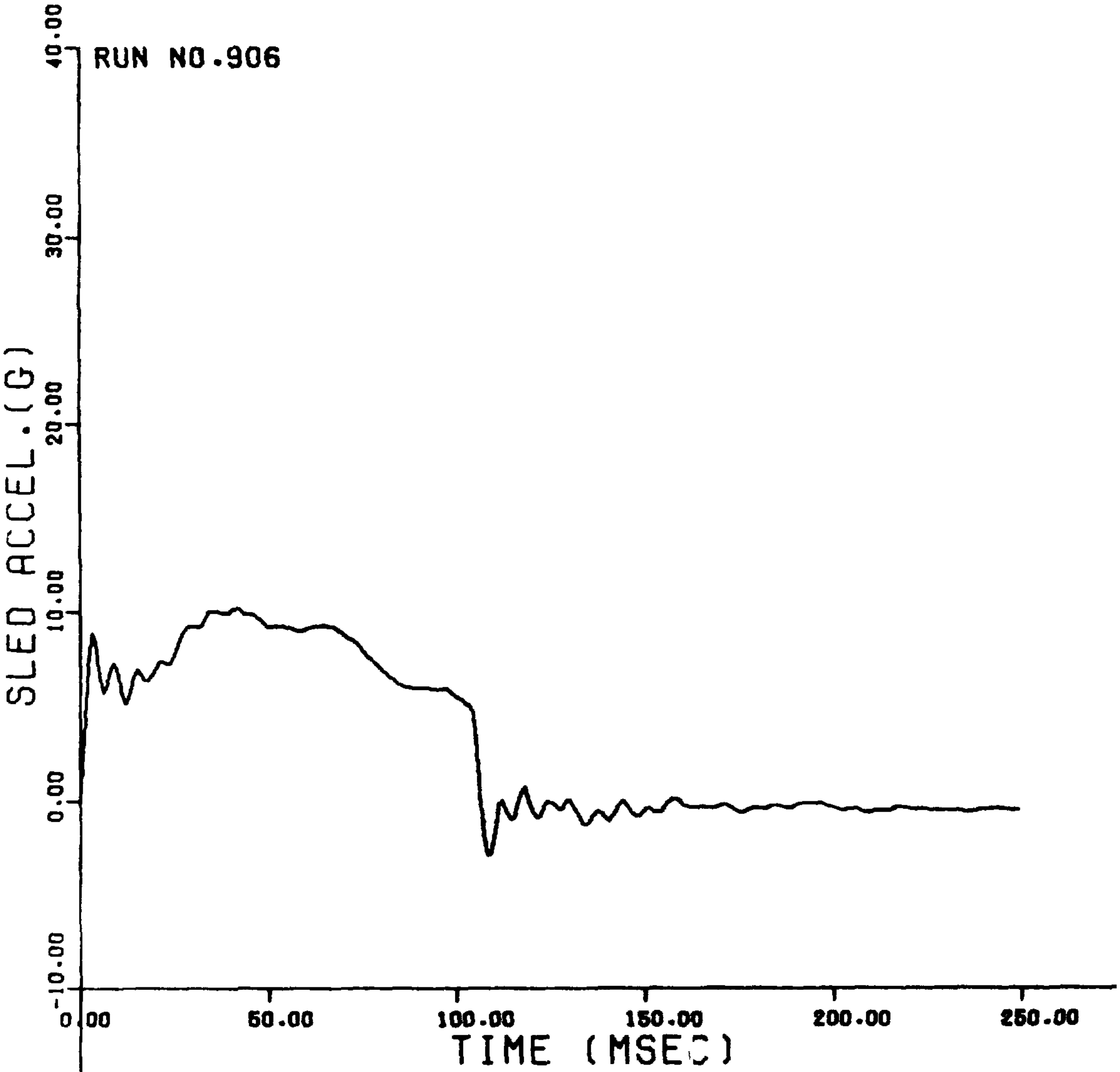
250.00
TIME (MSEC)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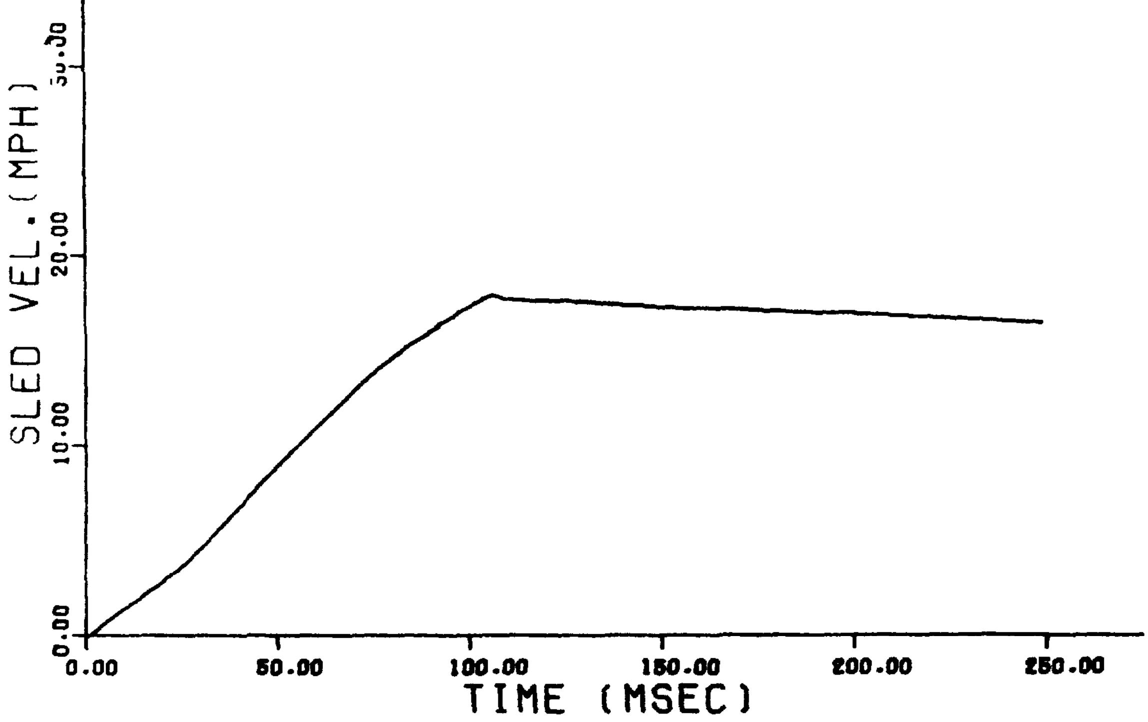
150.00
200.00
250.00
TIME (MSEC)


SLED VEL.(MPH)
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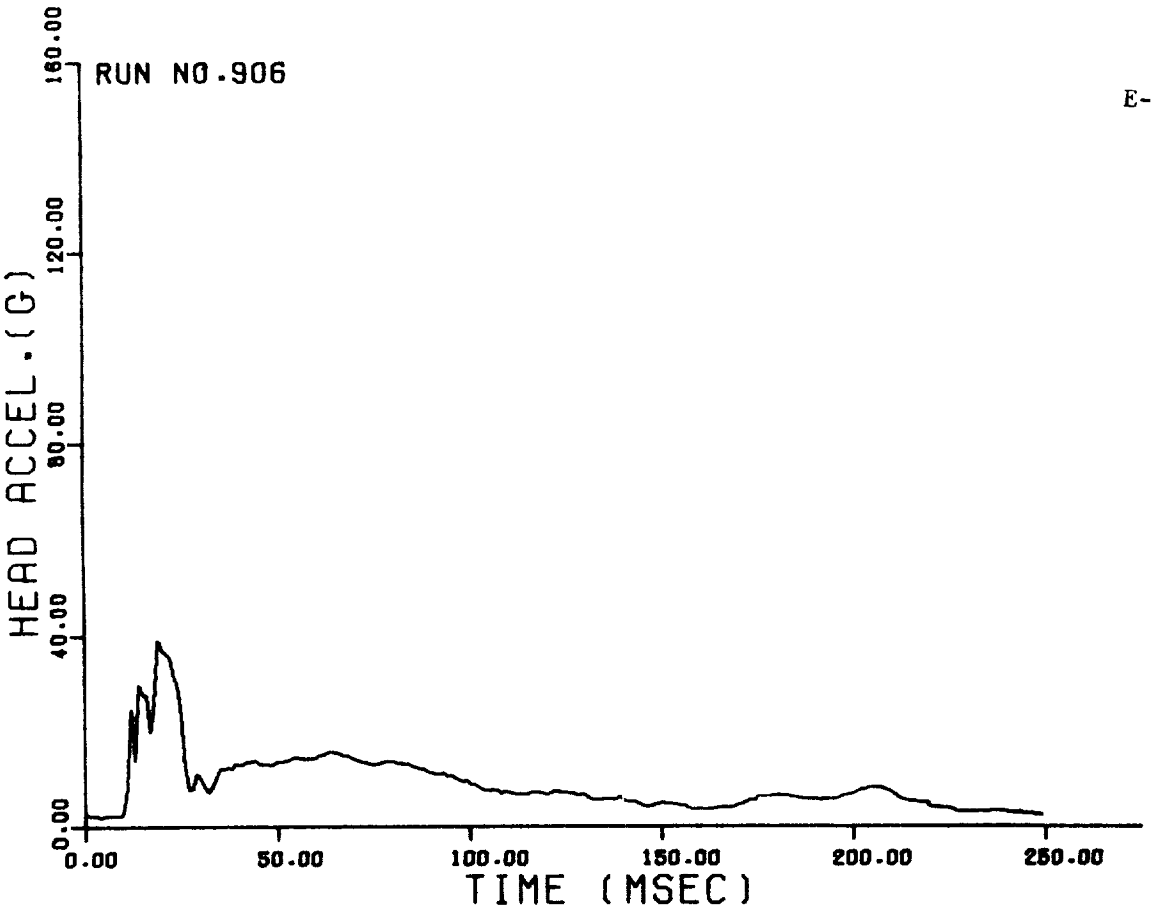
0.00
50.00
100.00
150.00
200.00
250.00
TIME (MSEC)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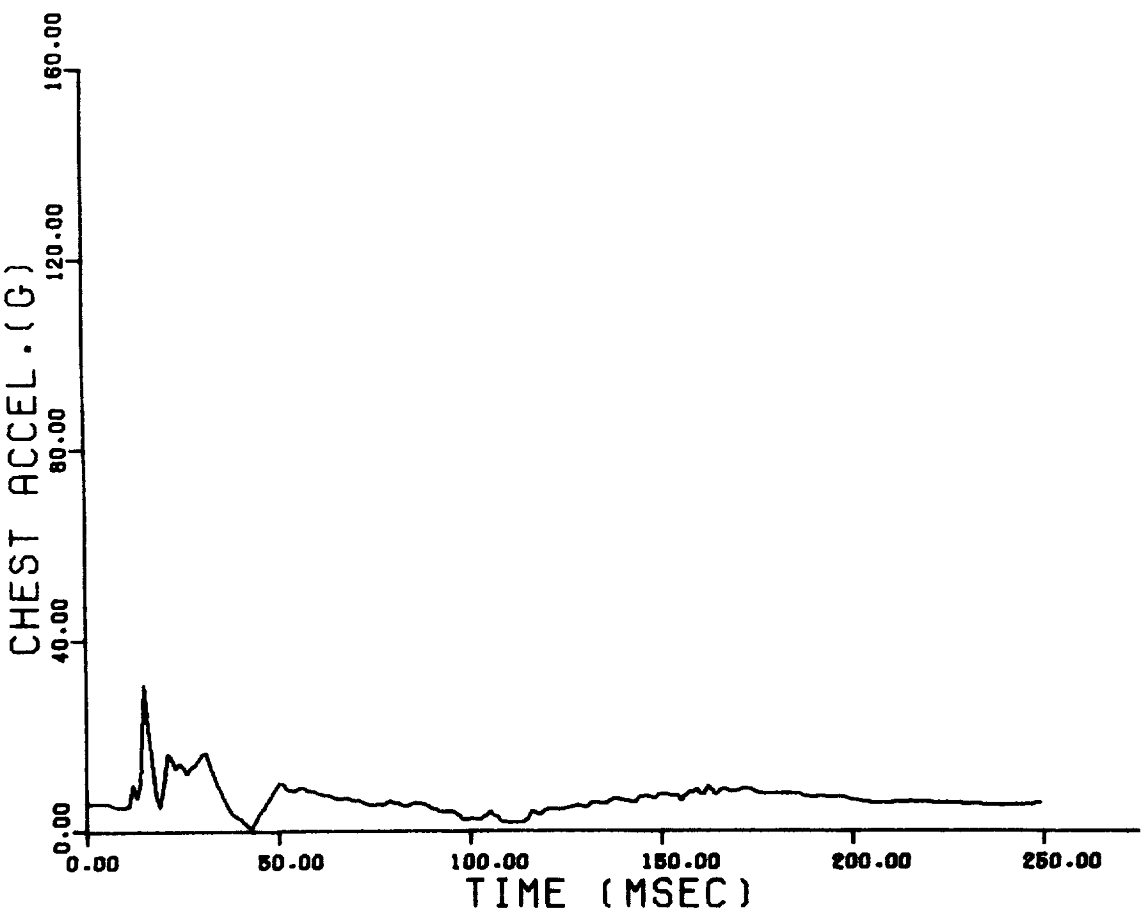
250.00
TIME (MSEC)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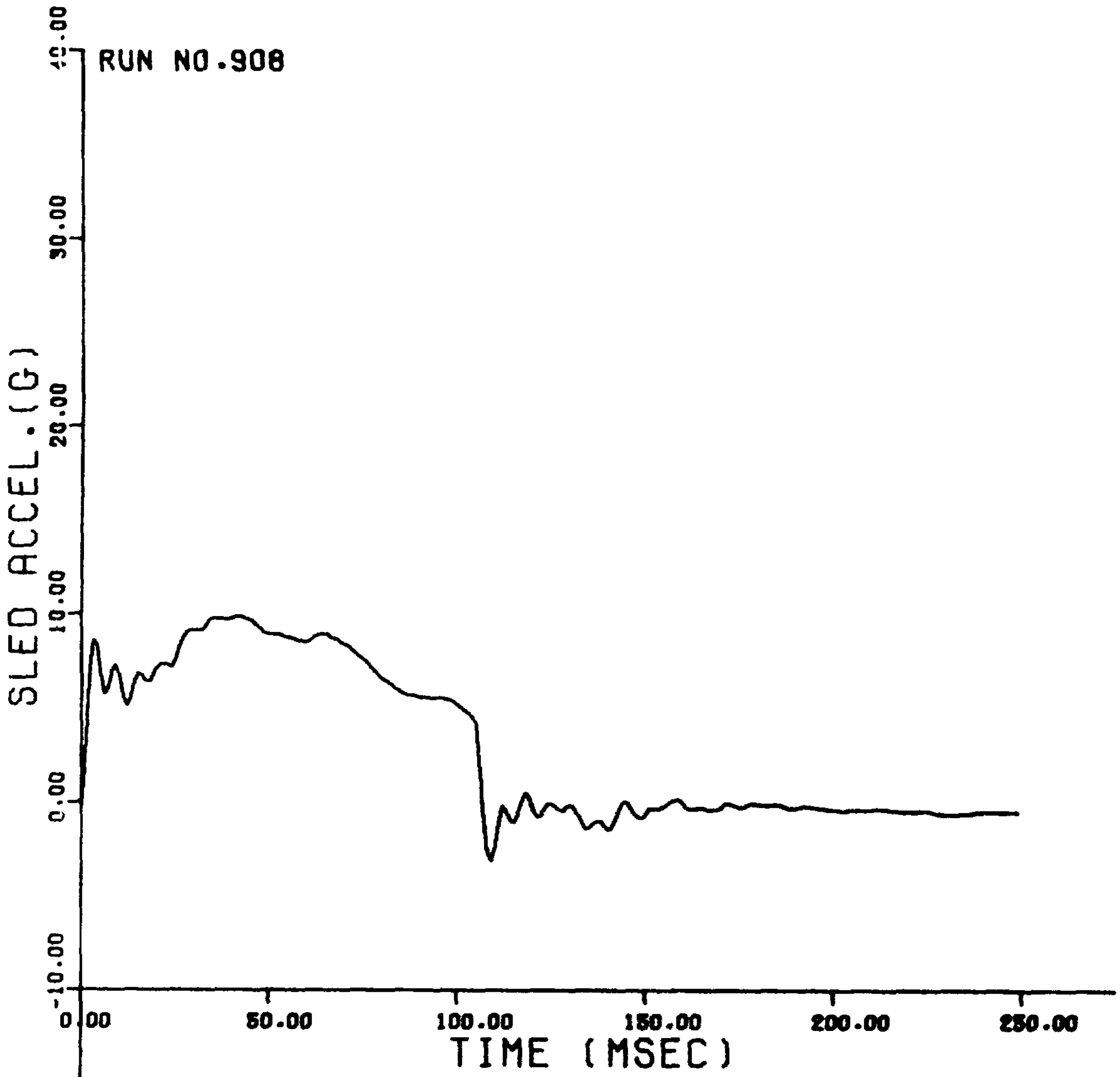
200.00
250.00
TIME (MSEC)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30.00
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150.00
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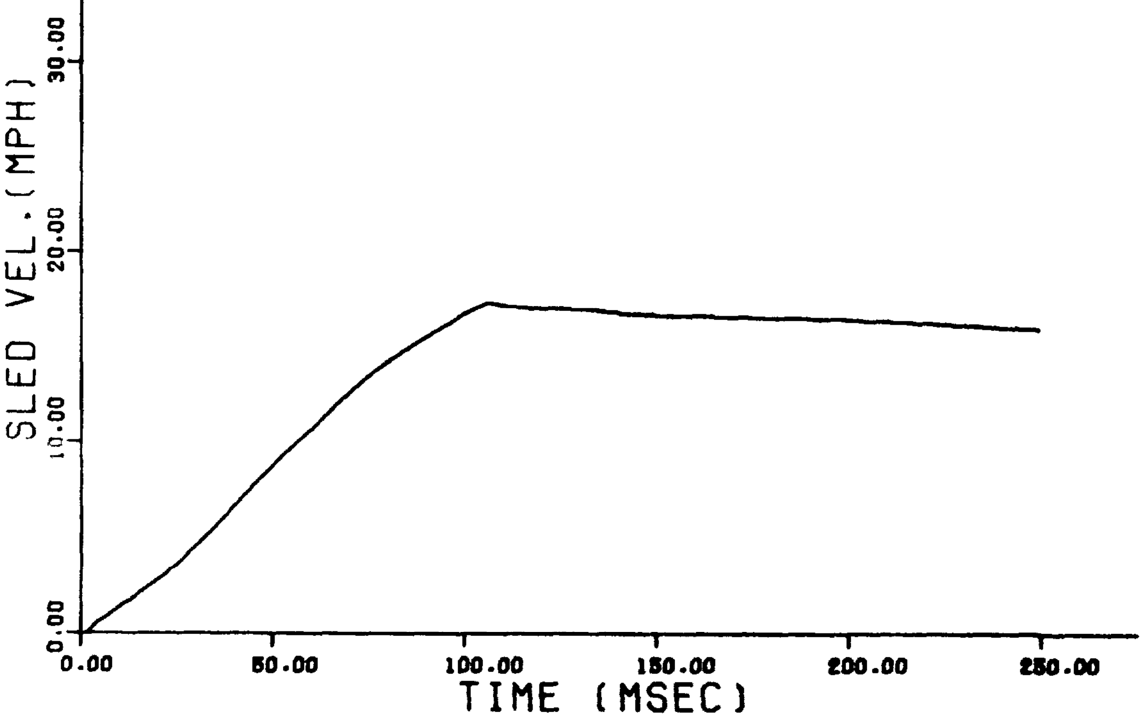
250.00
TIME (MSEC)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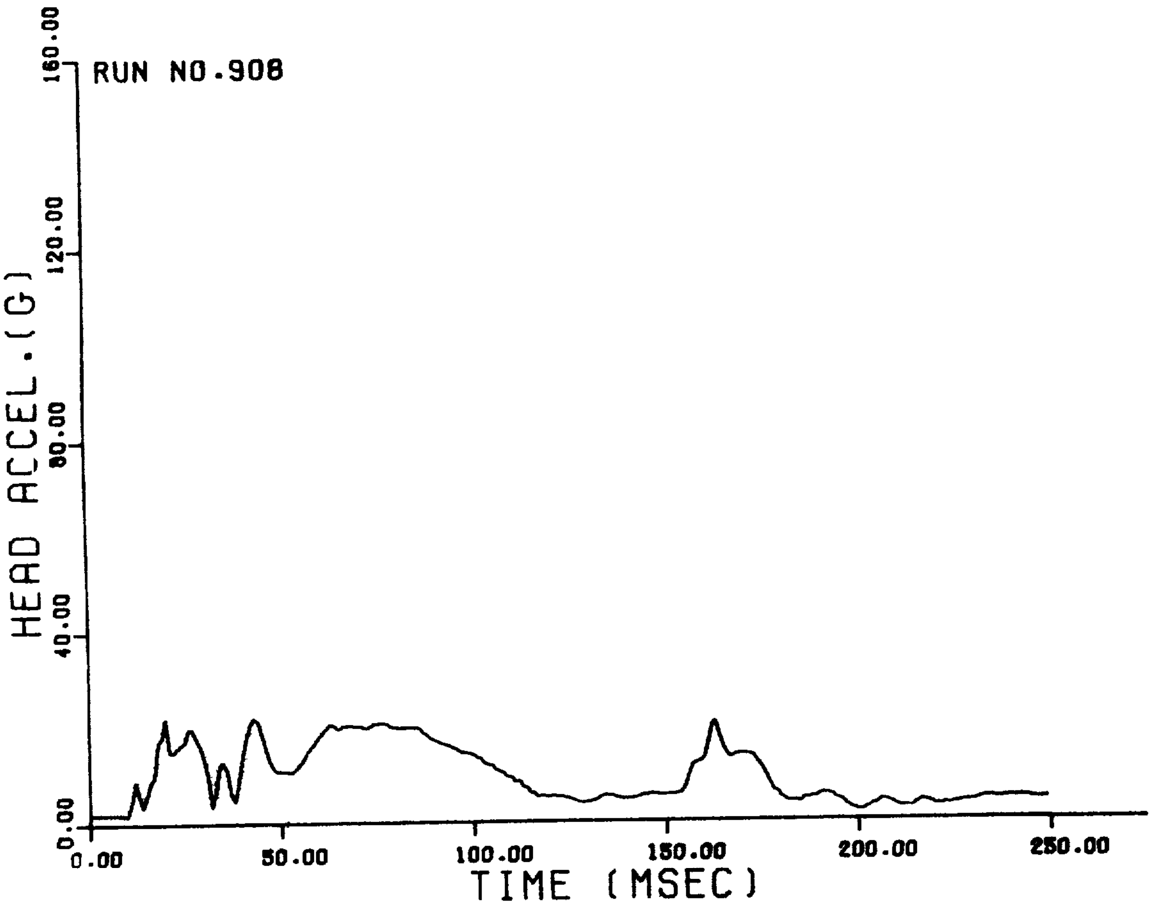
TIME (MSEC)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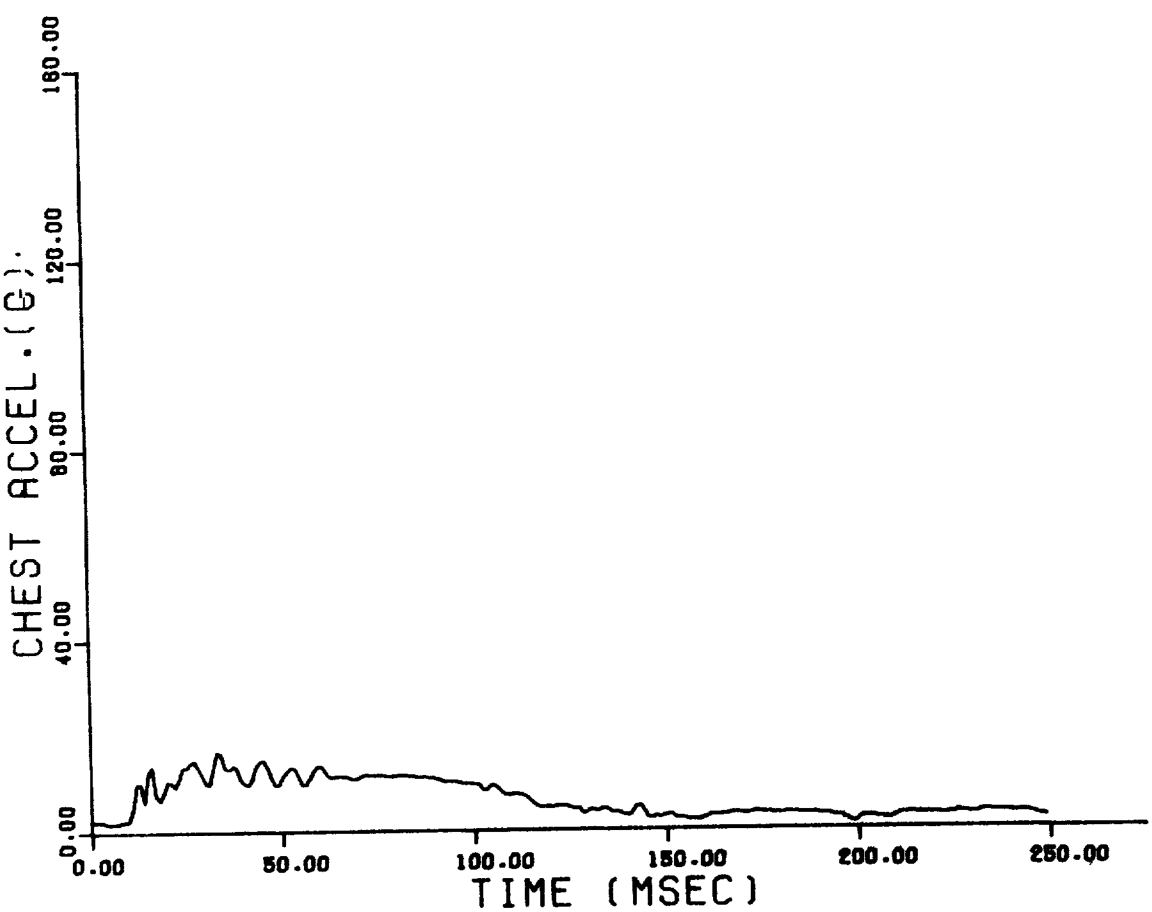
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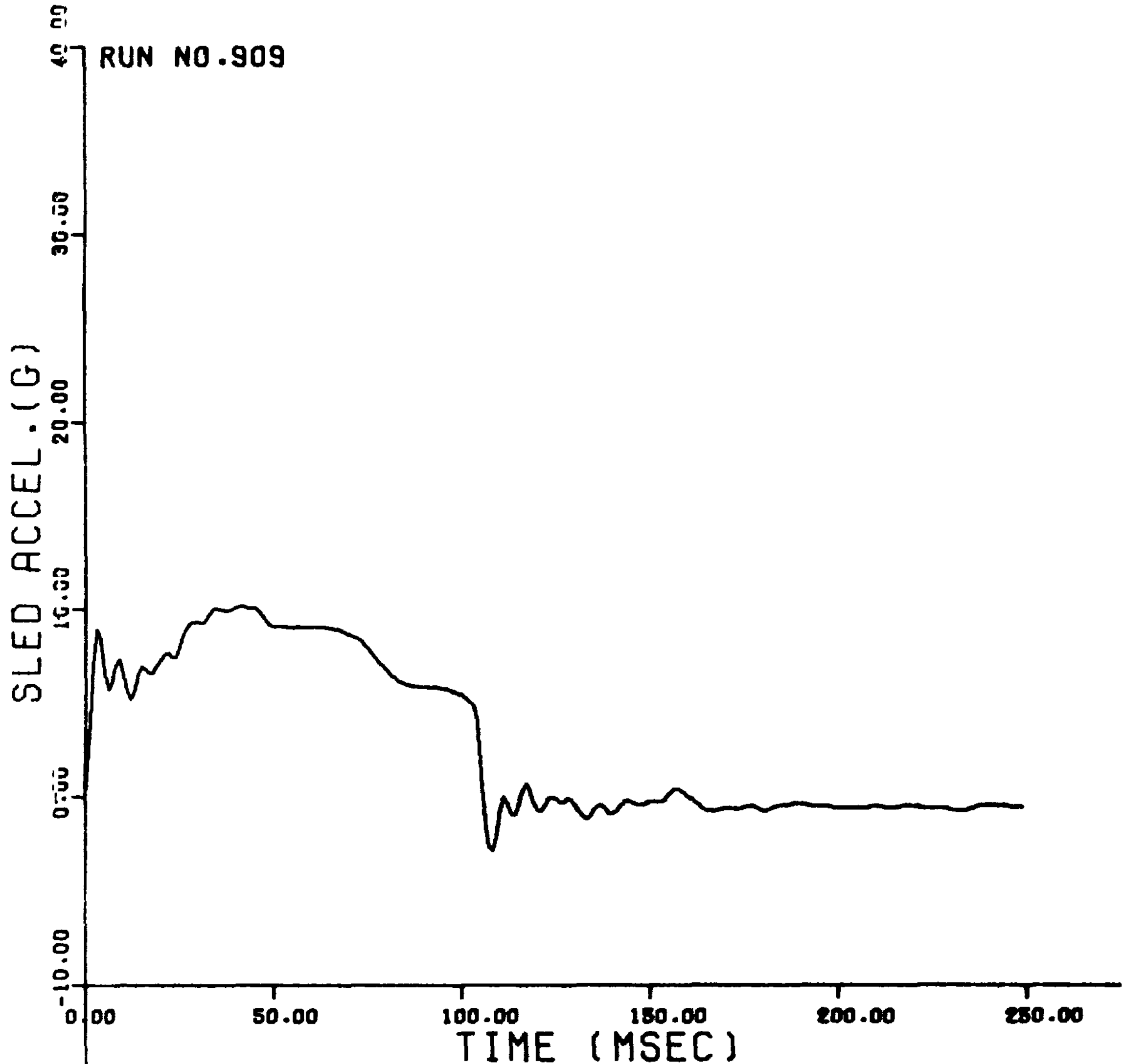
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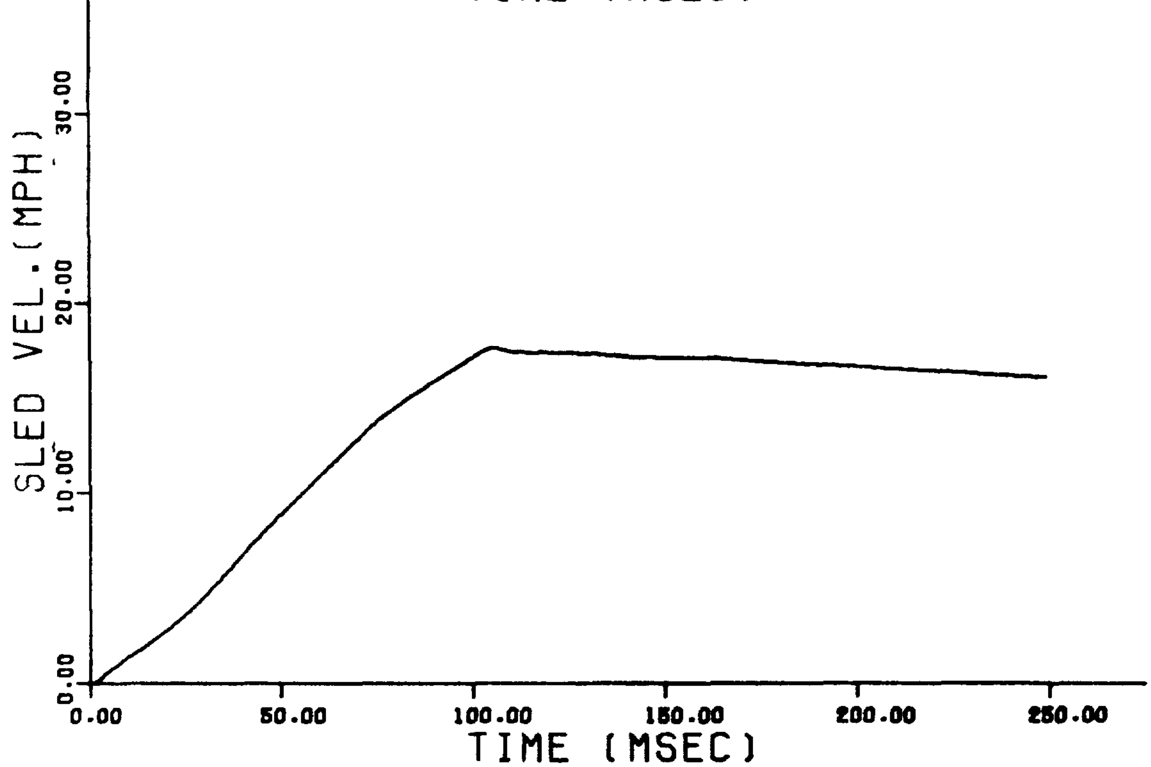
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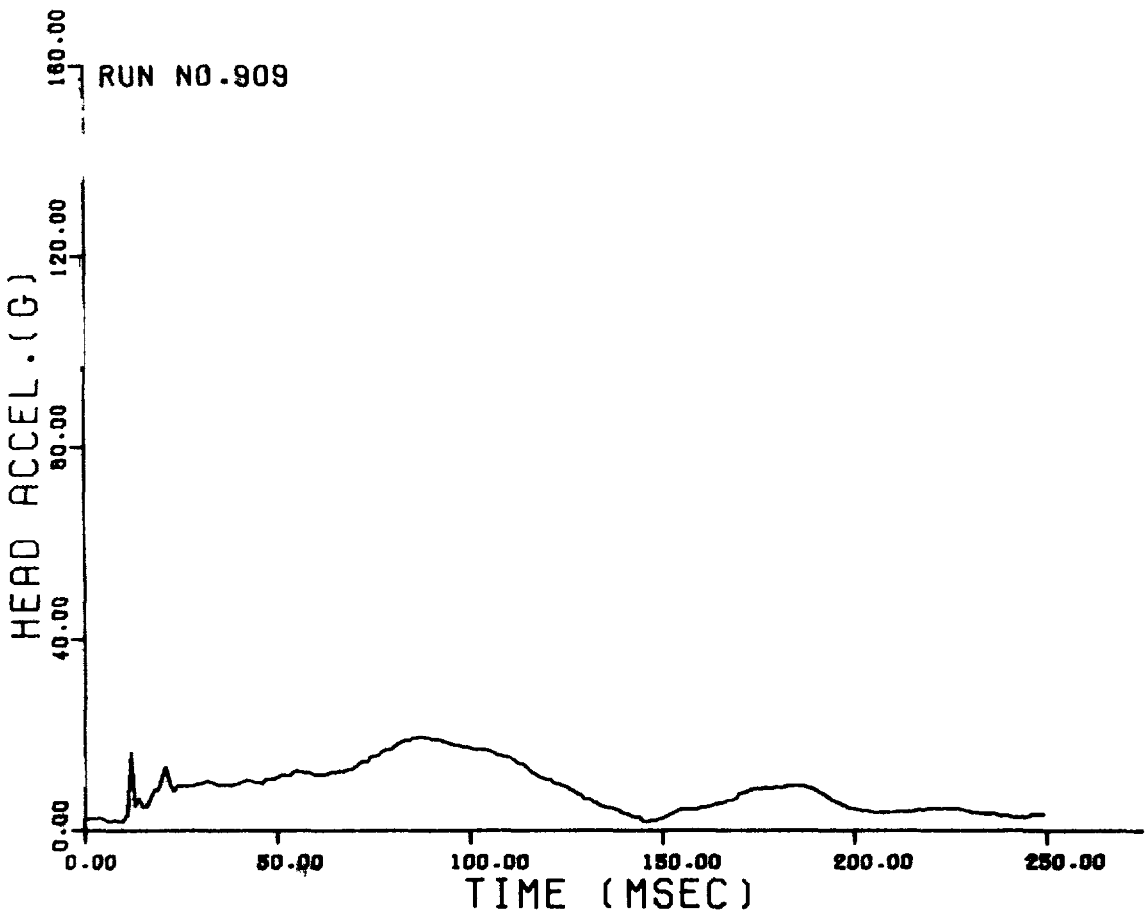
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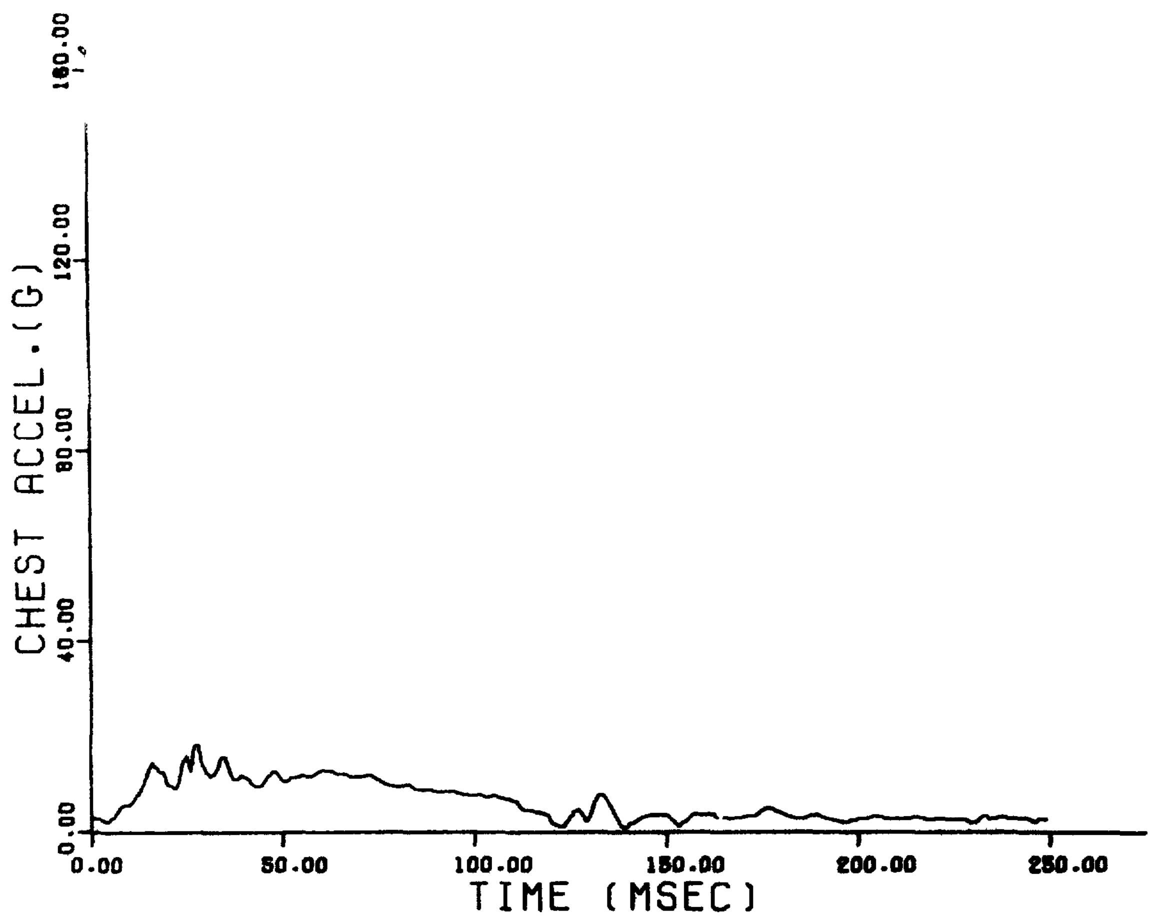
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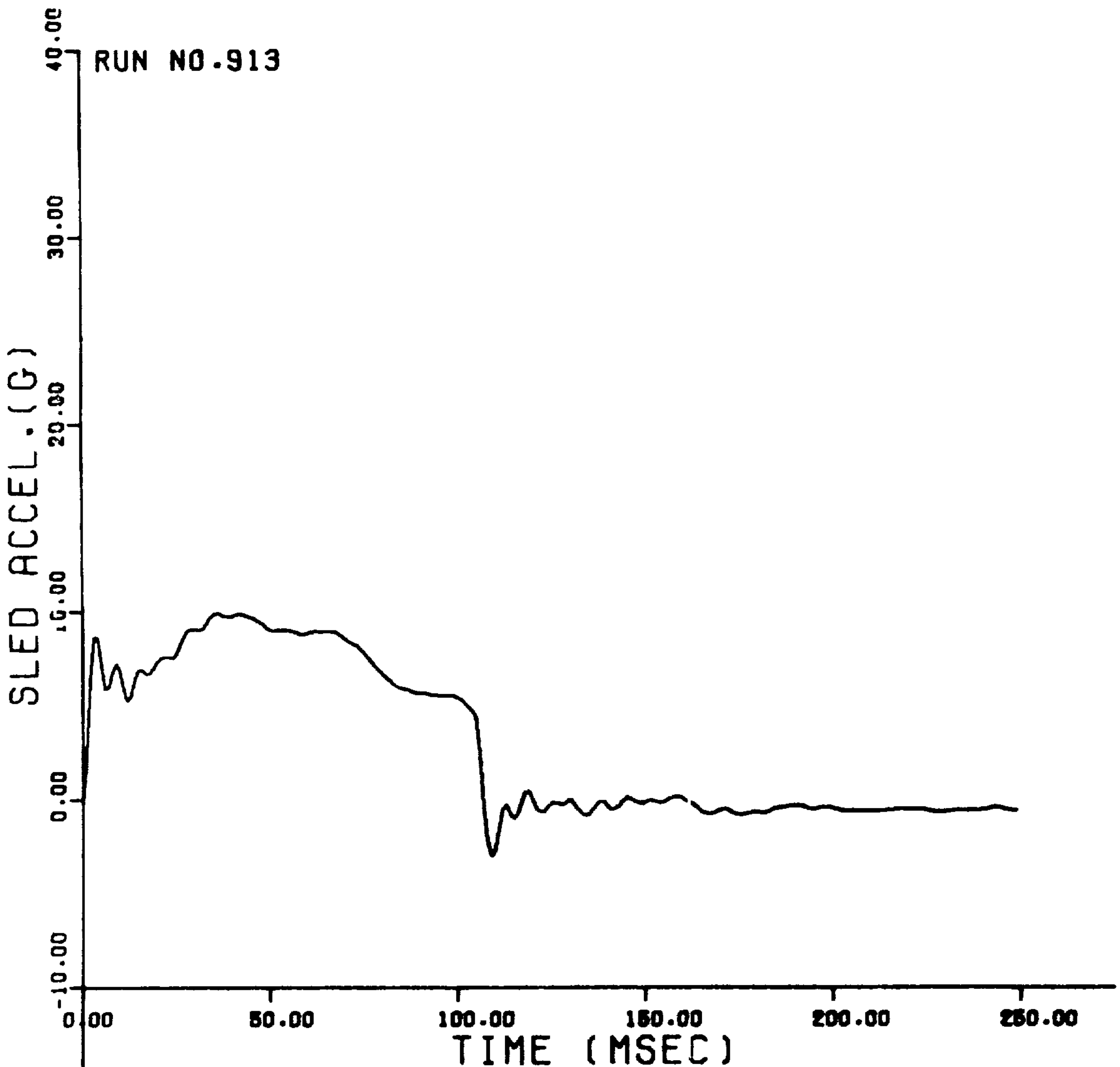
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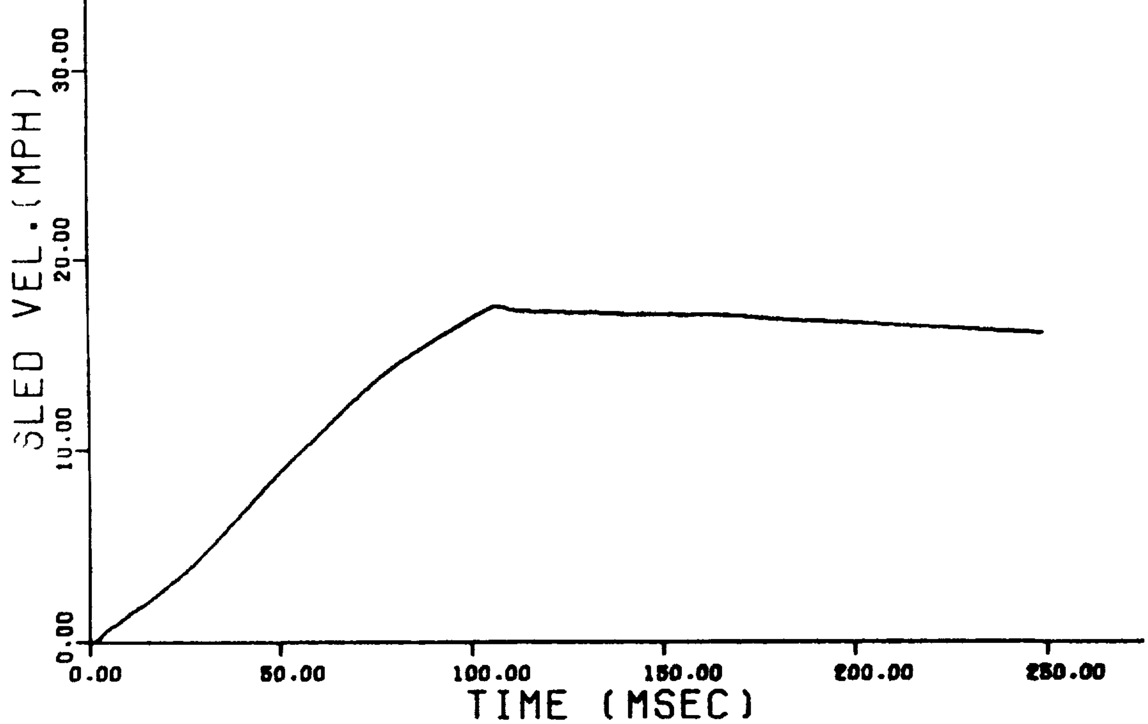
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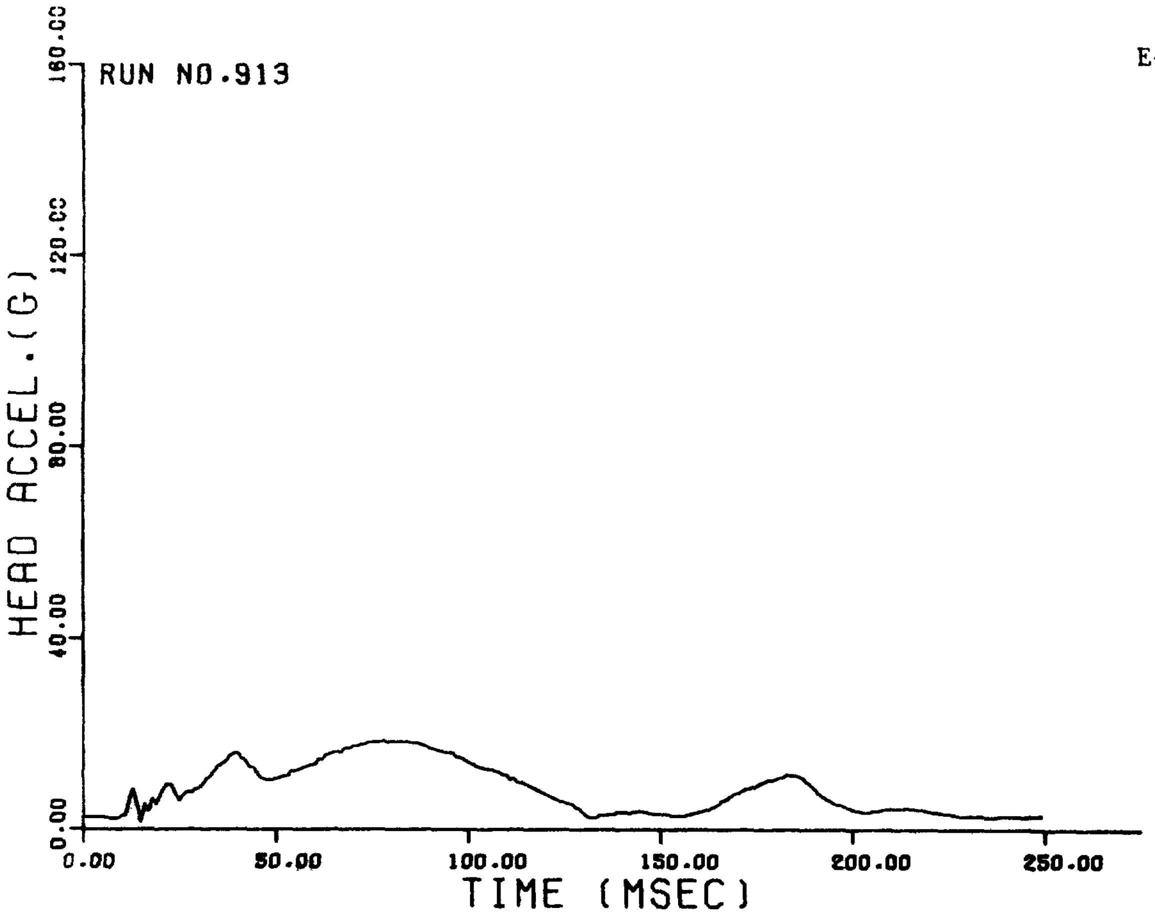
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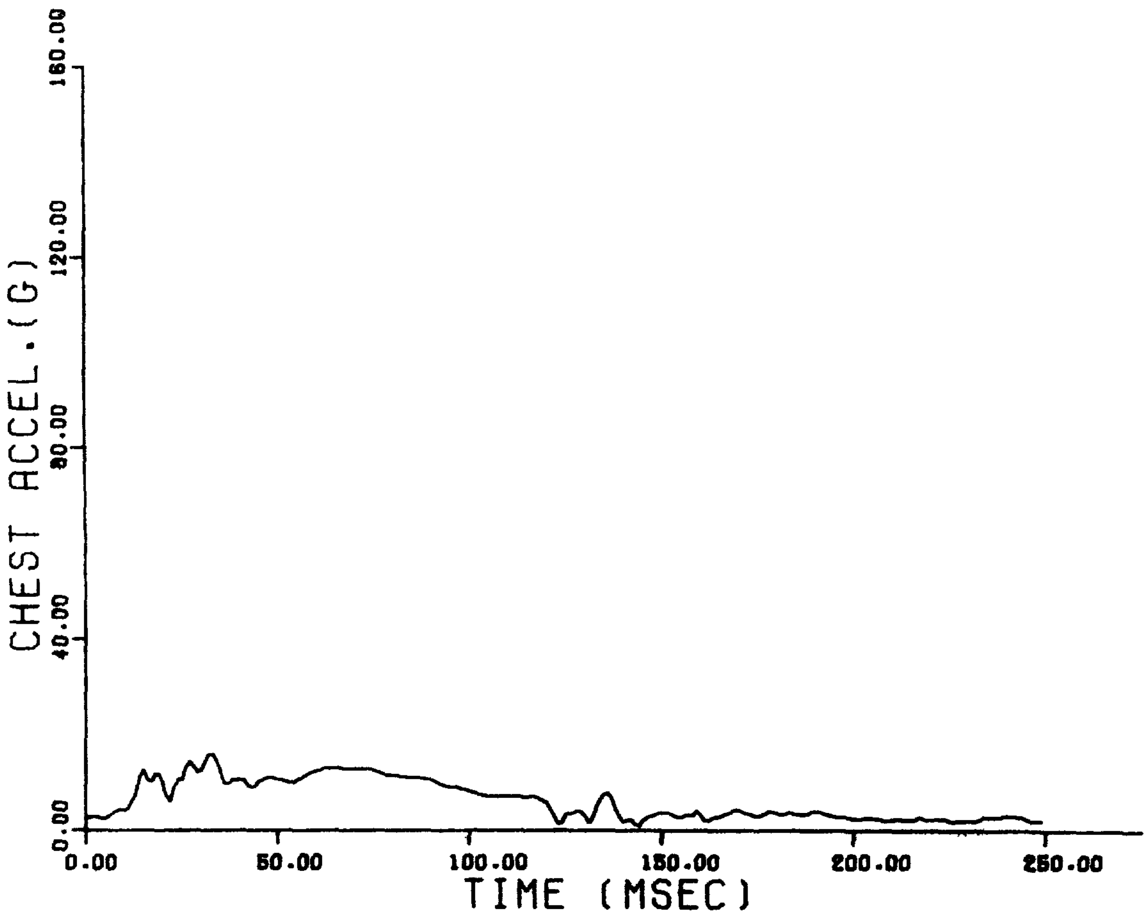
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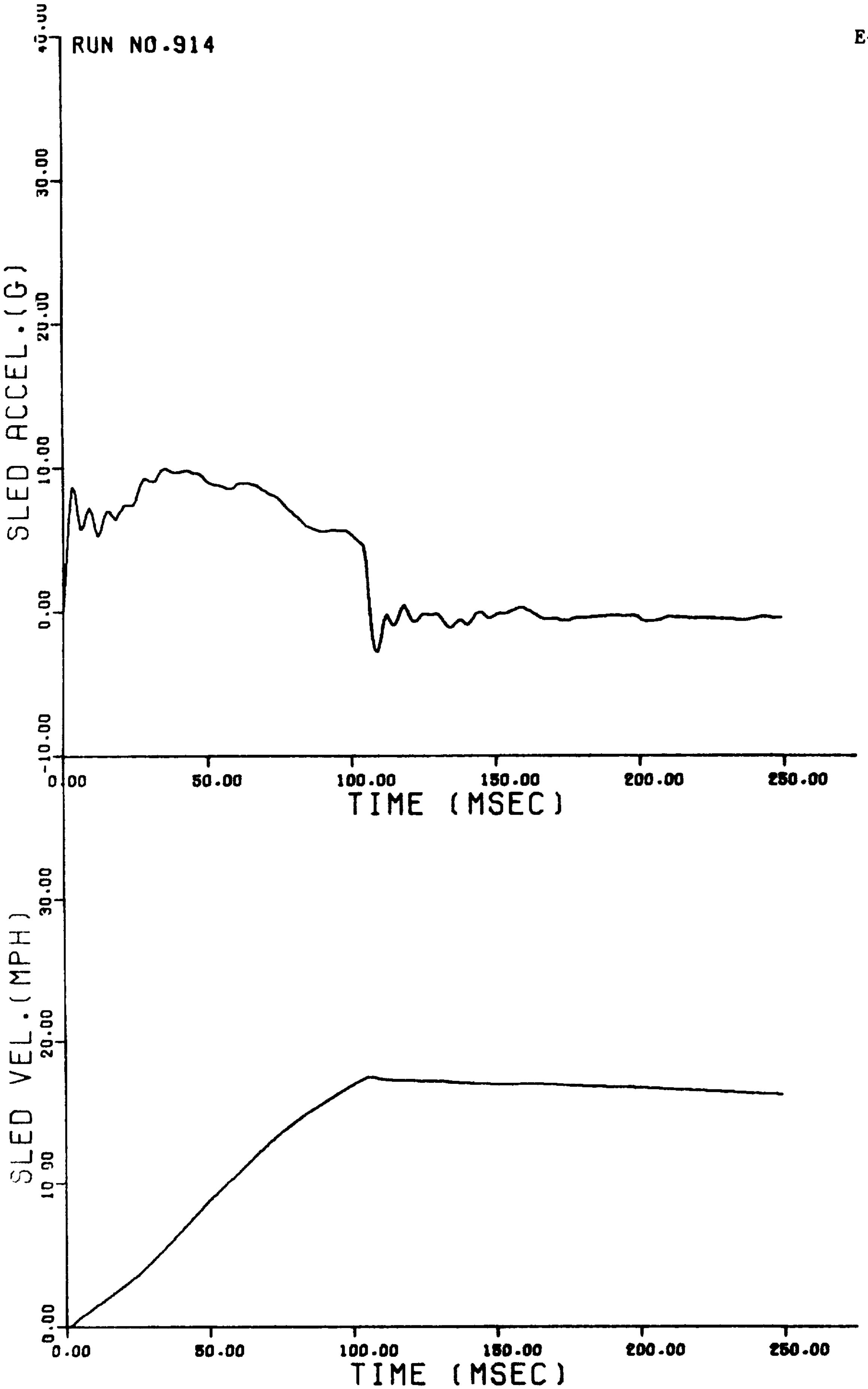
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TIME (MSEC)
SLED VEL.(MPH)
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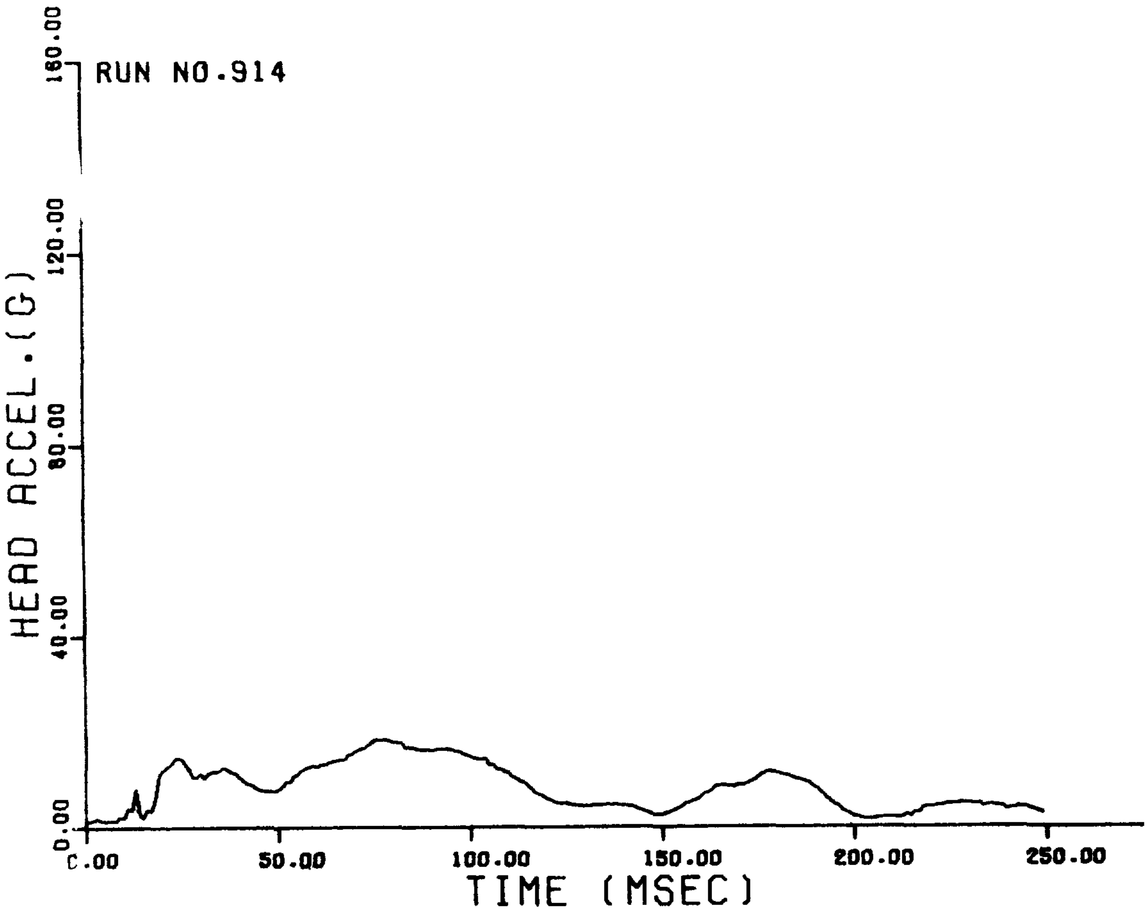
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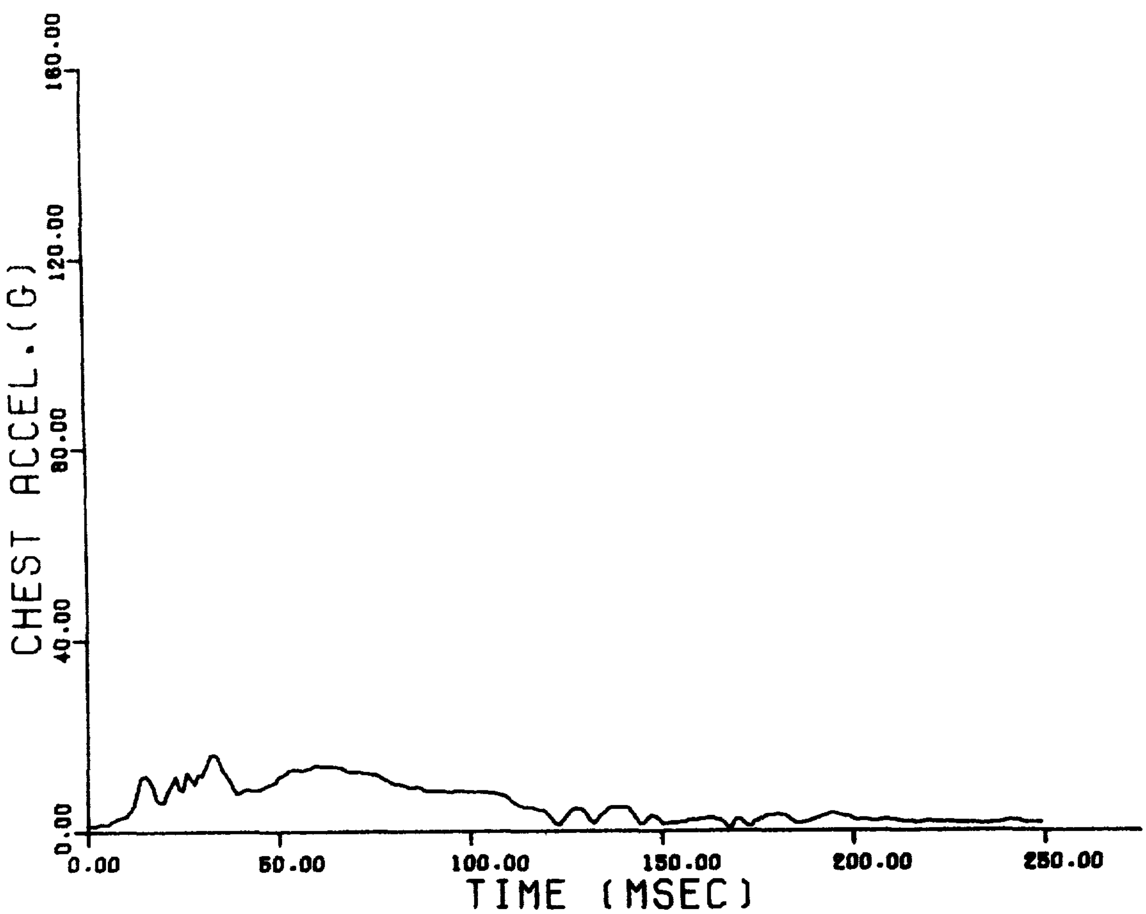
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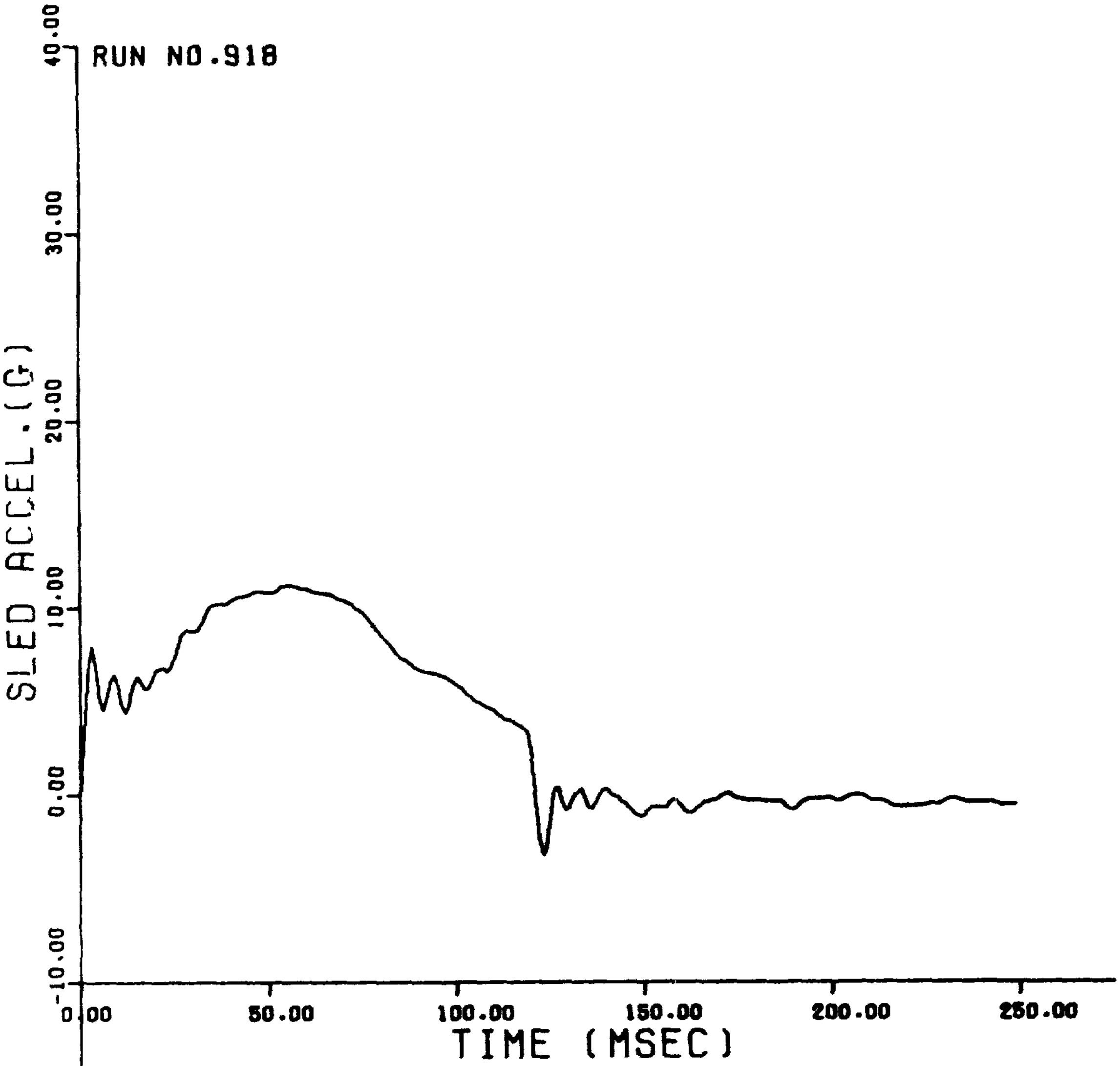
TIME (MSEC)

F 3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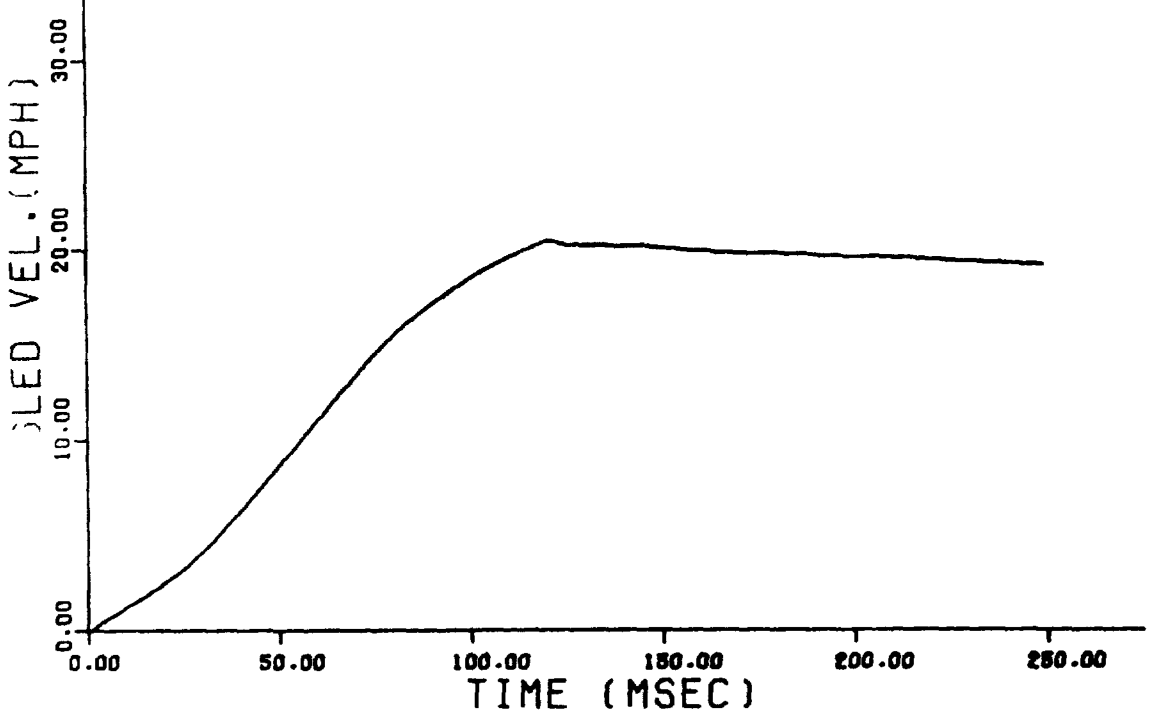
TIME (MSEC)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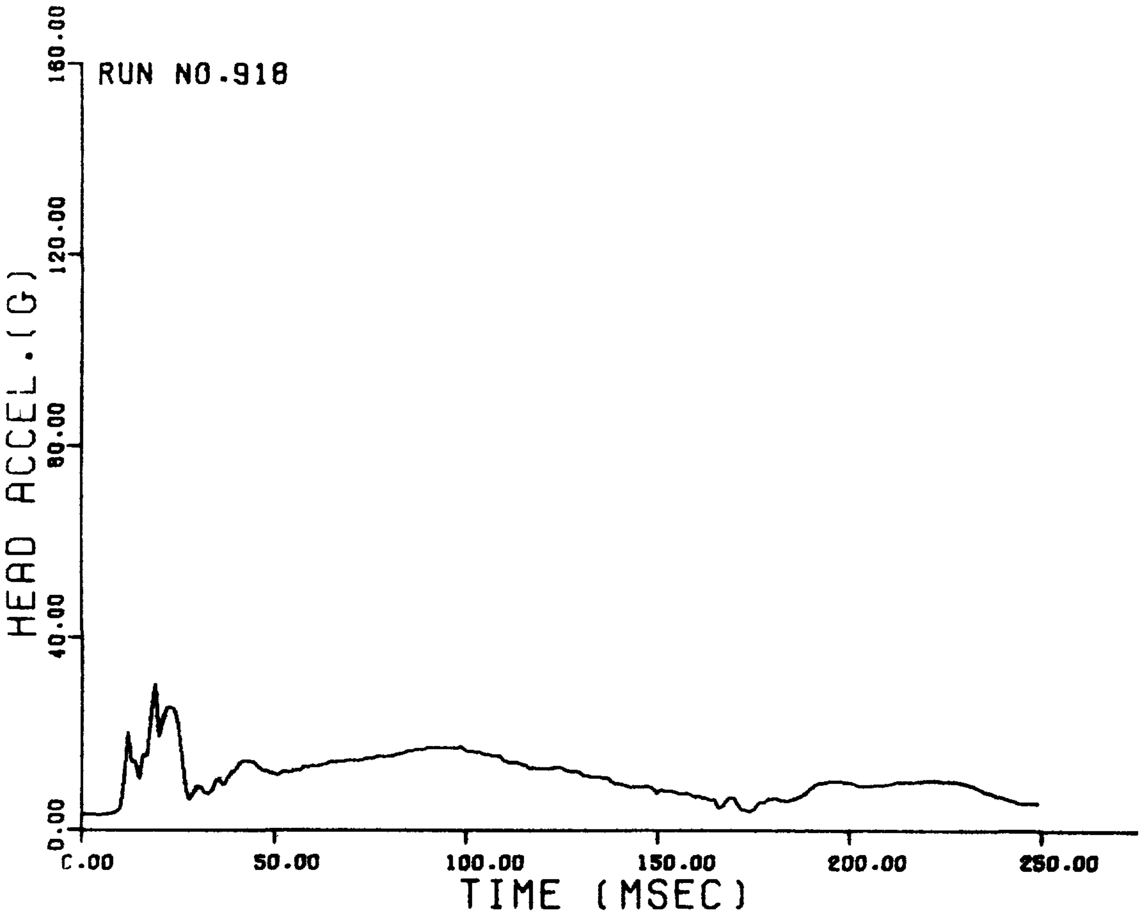
TIME (MSEC)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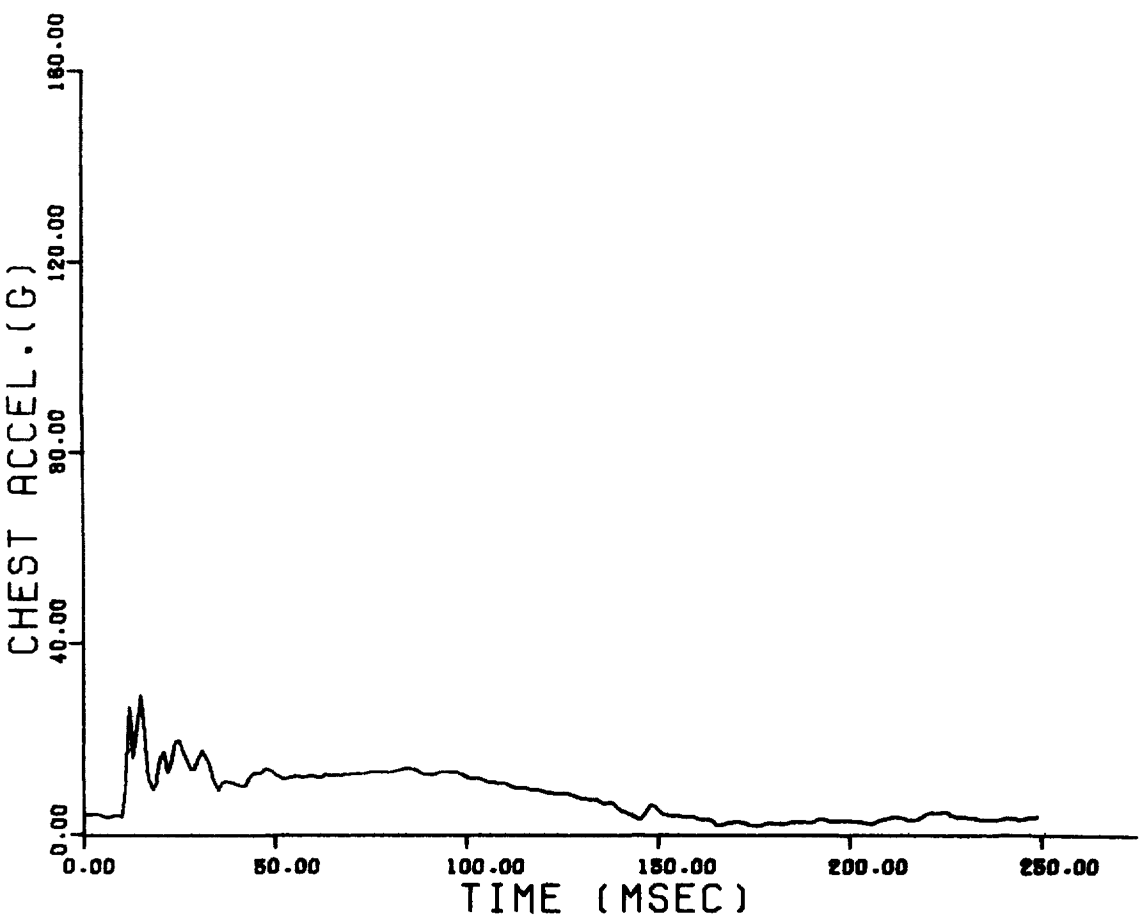
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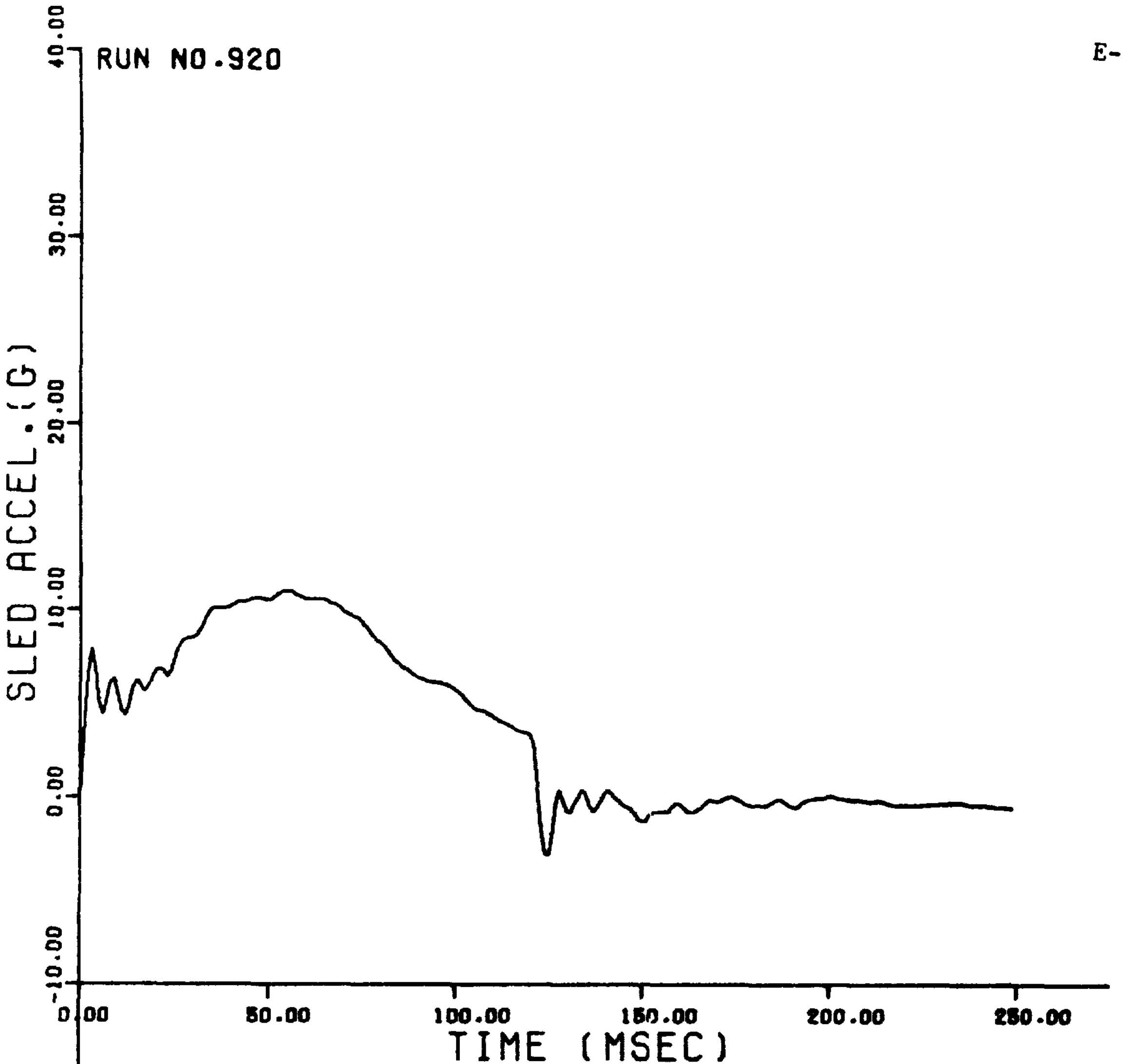
TIME (MSEC)



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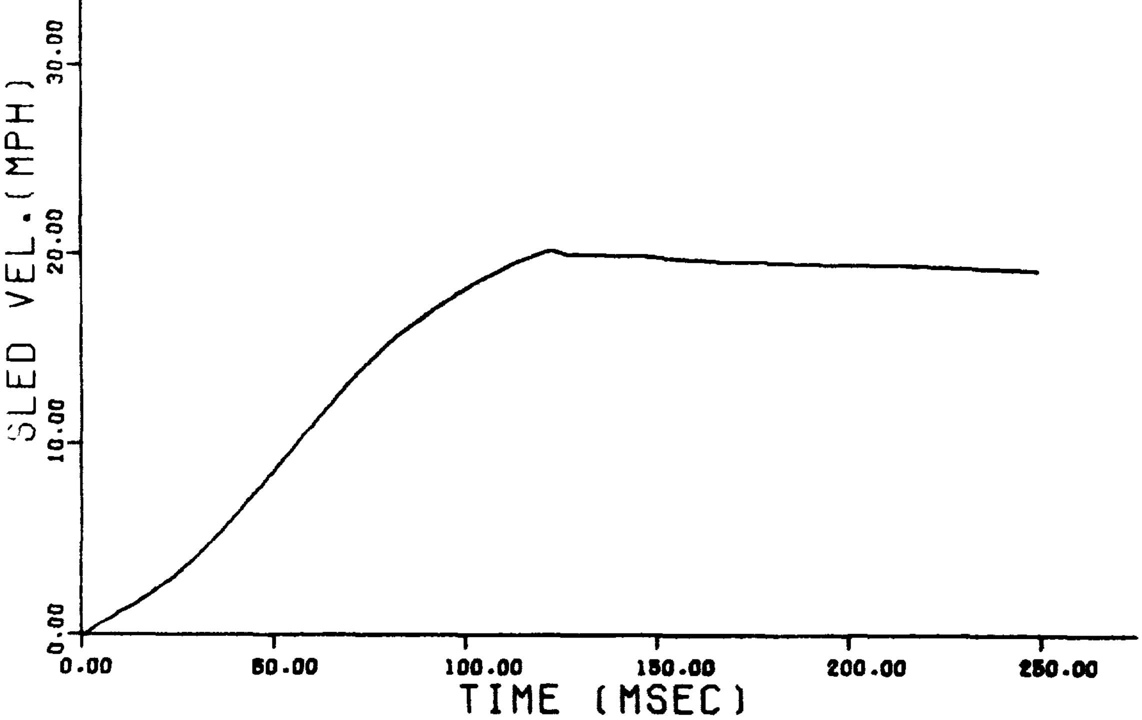

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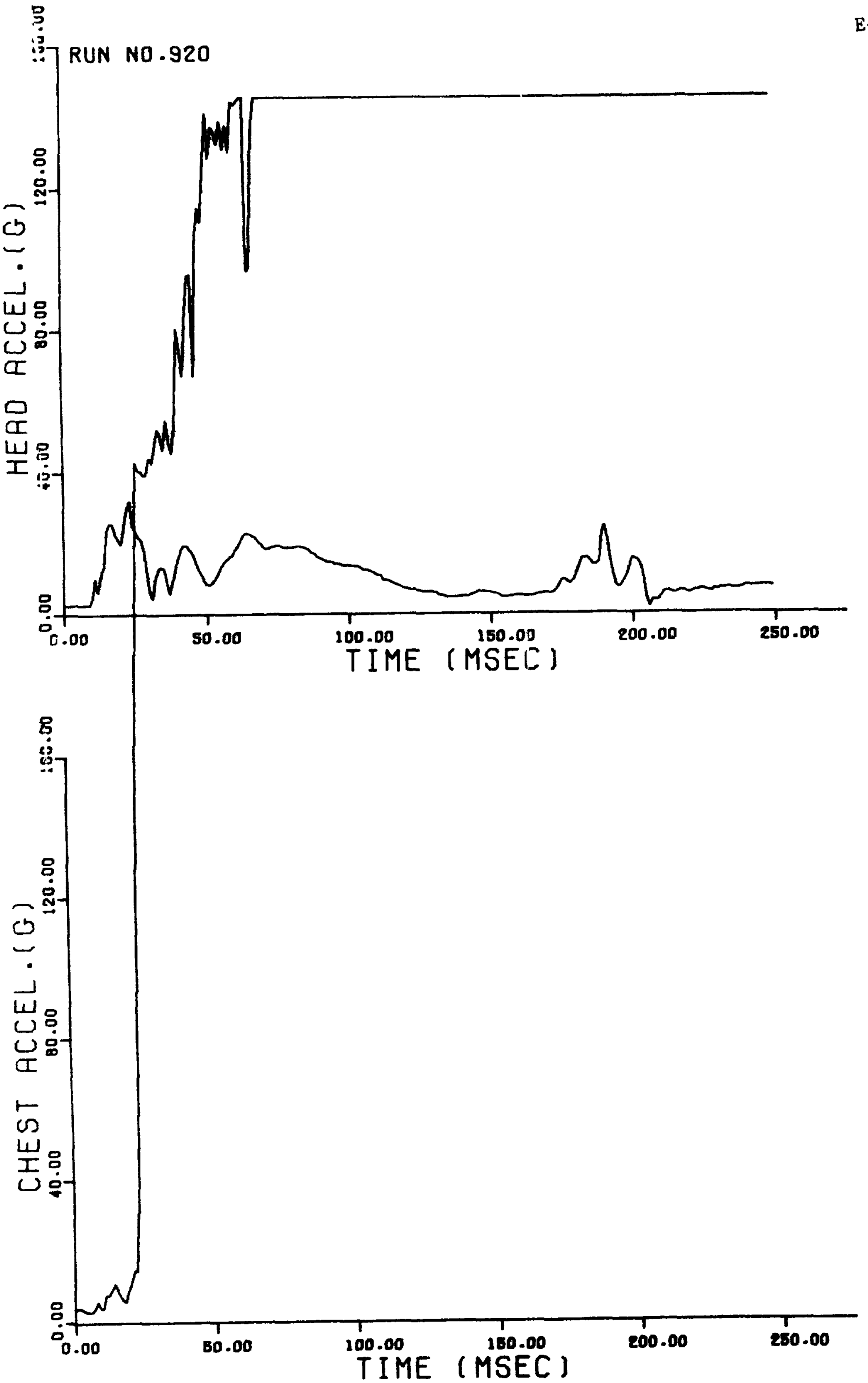
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TIME (MSEC)
CHEST ACCEL.(G)
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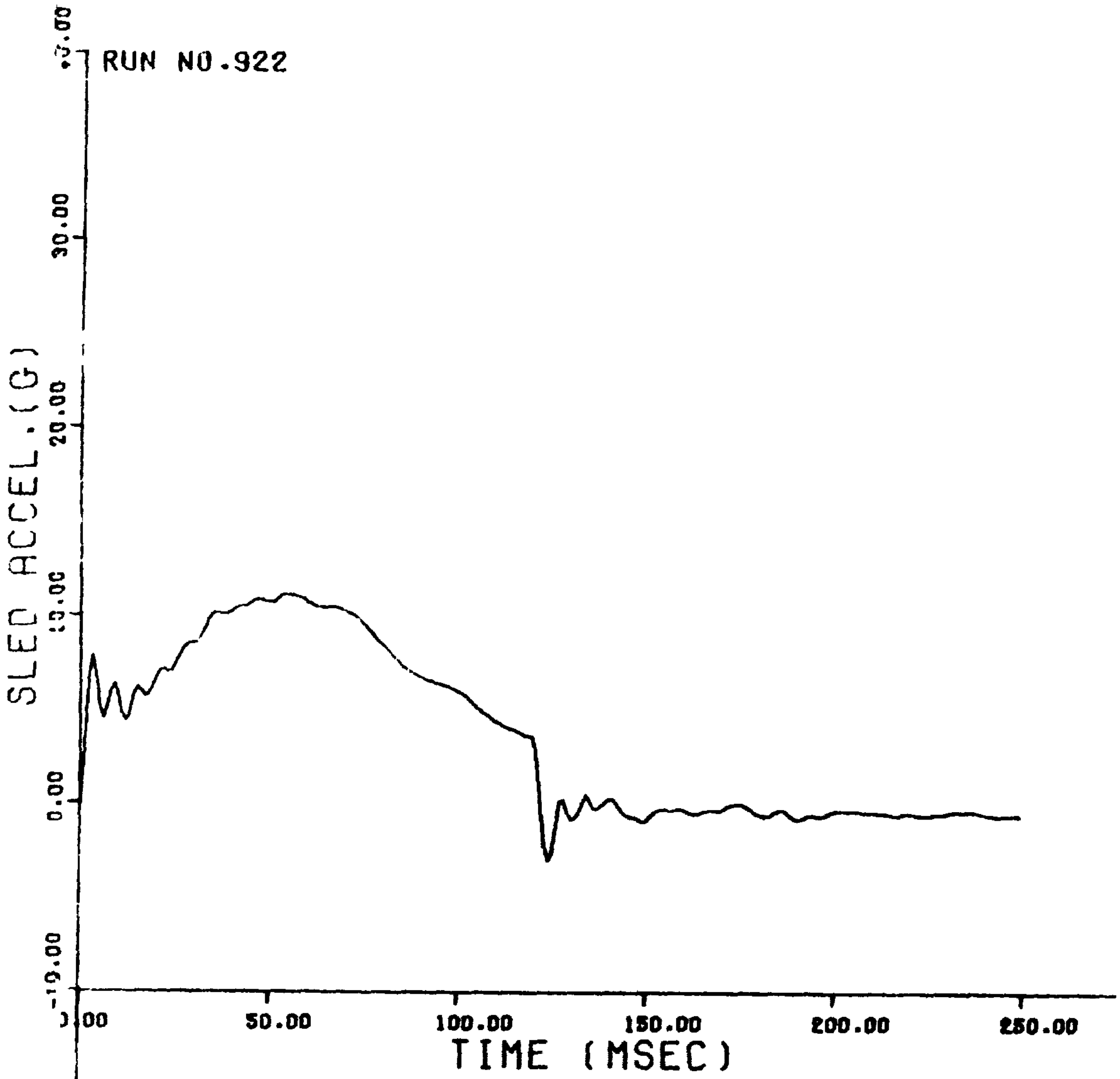
TIME (MSEC)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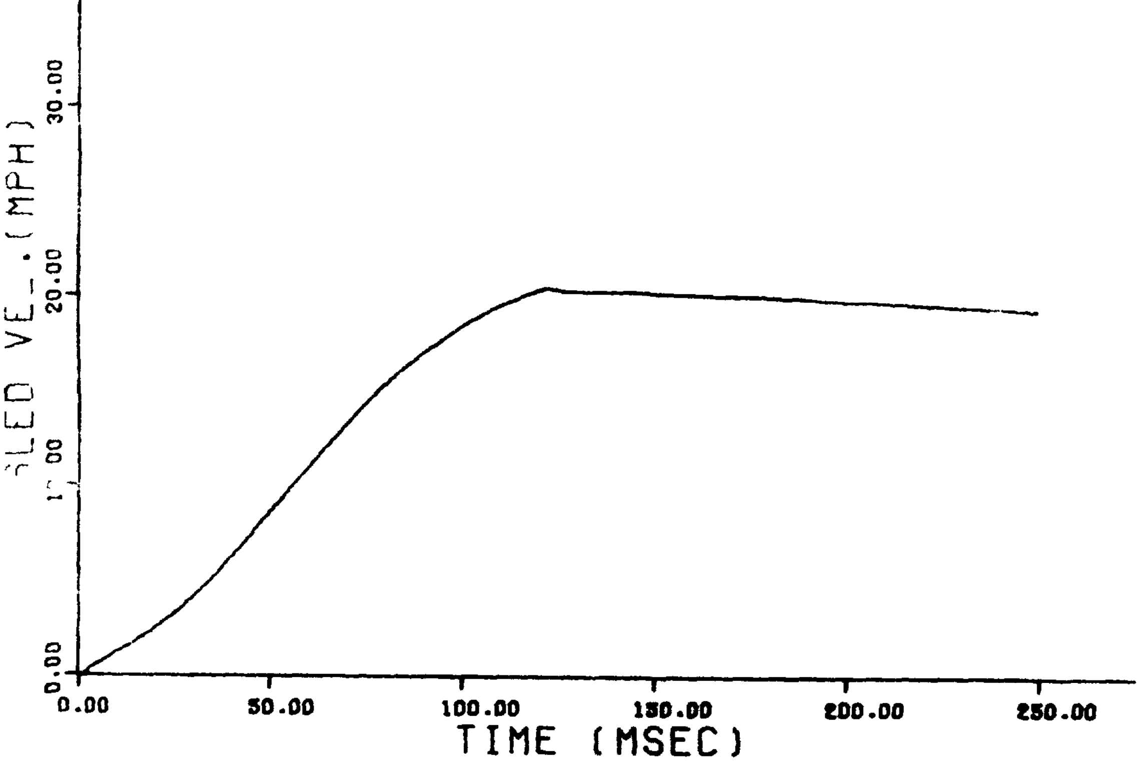
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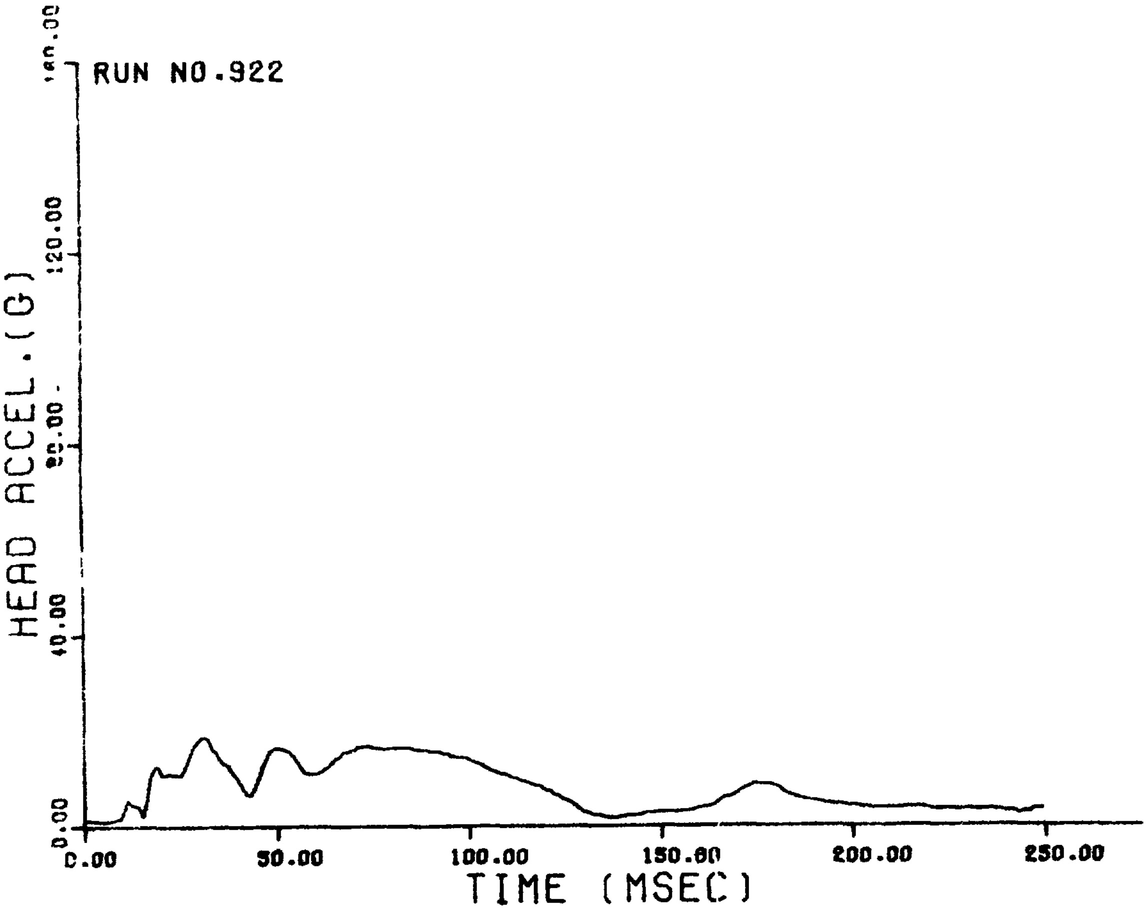
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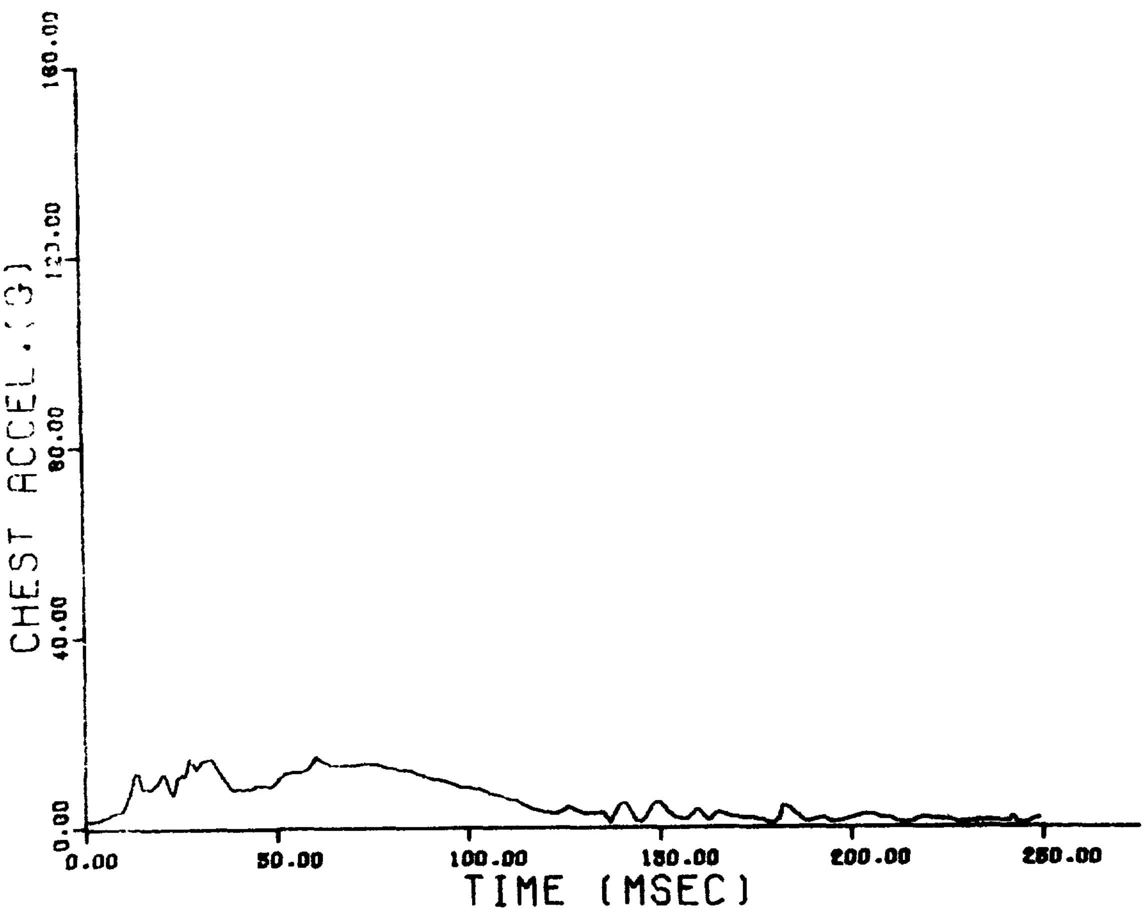
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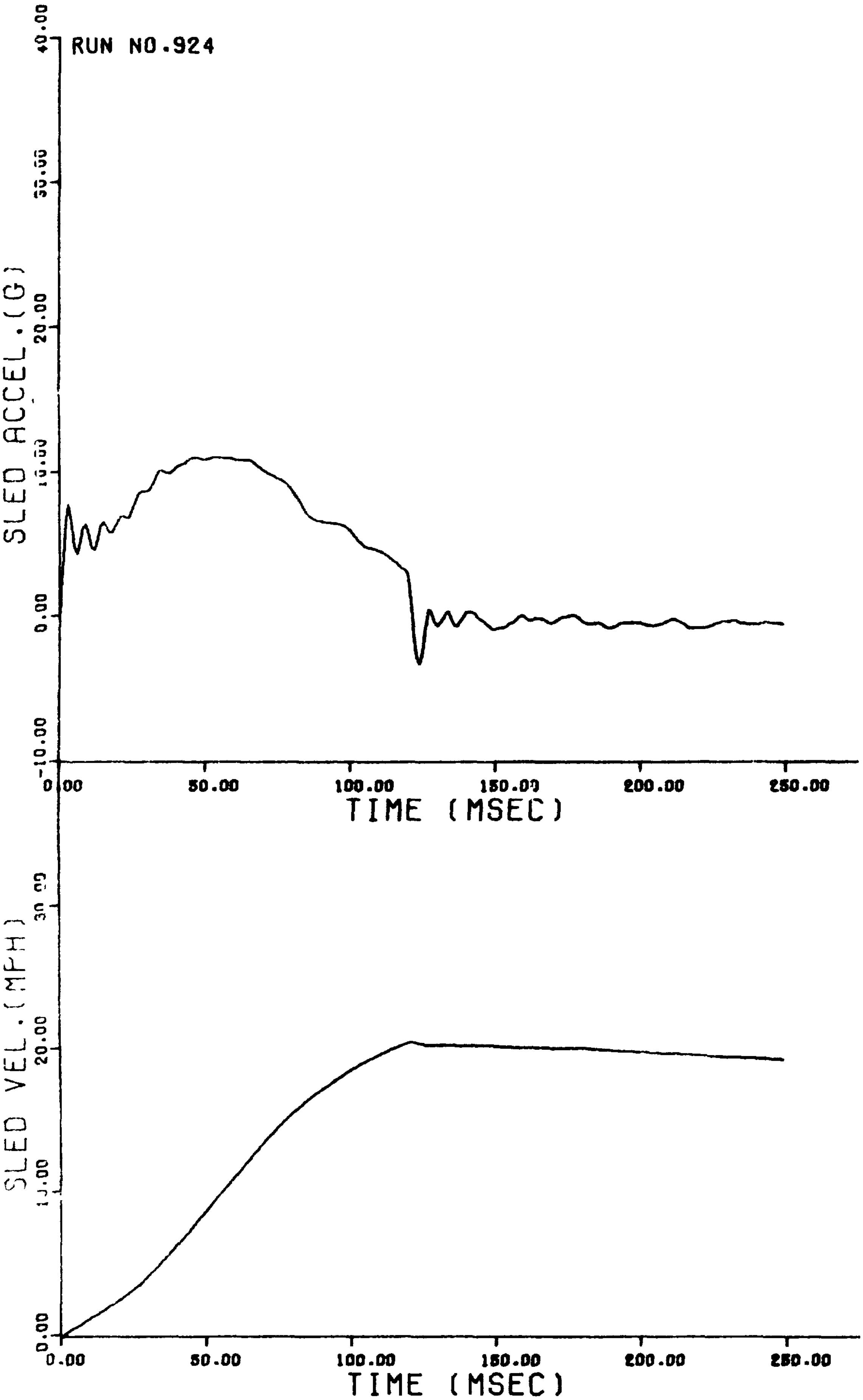
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TIME (MSEC)
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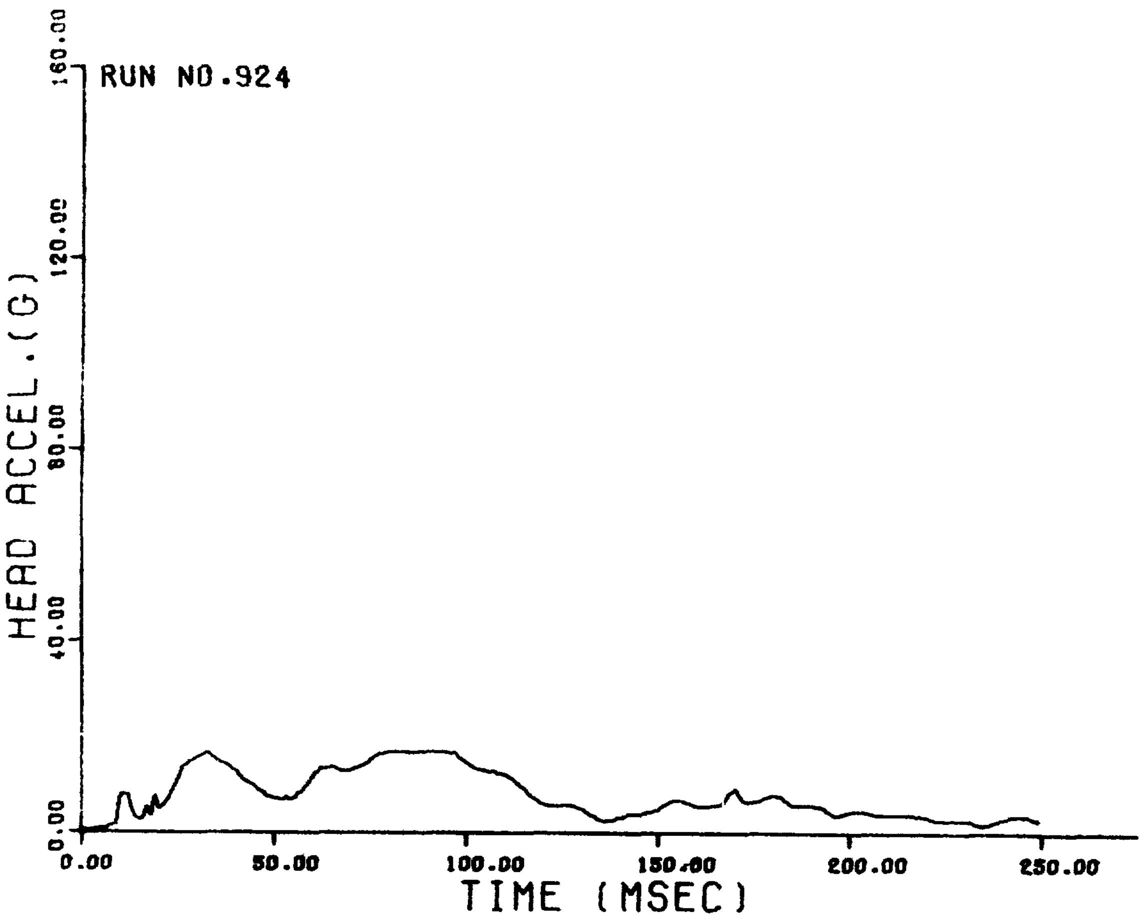
TIME (MSEC)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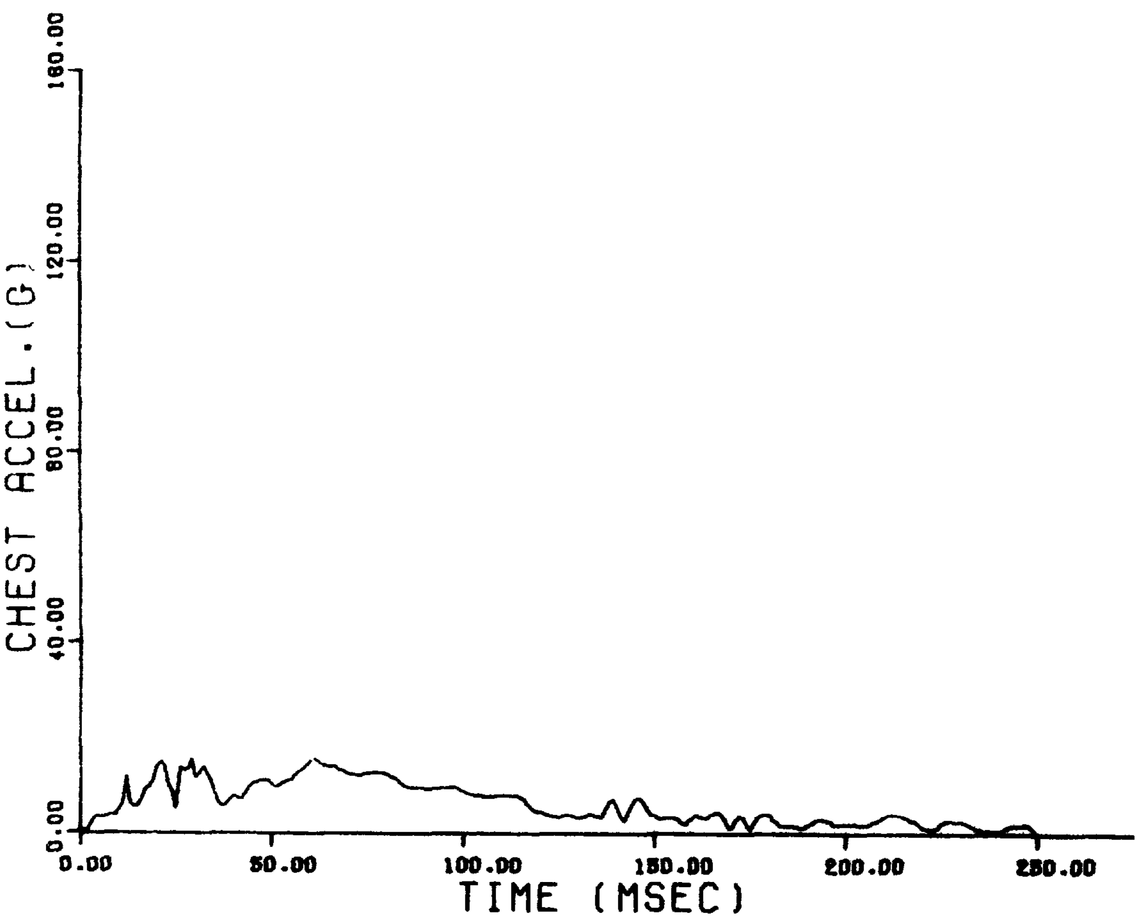
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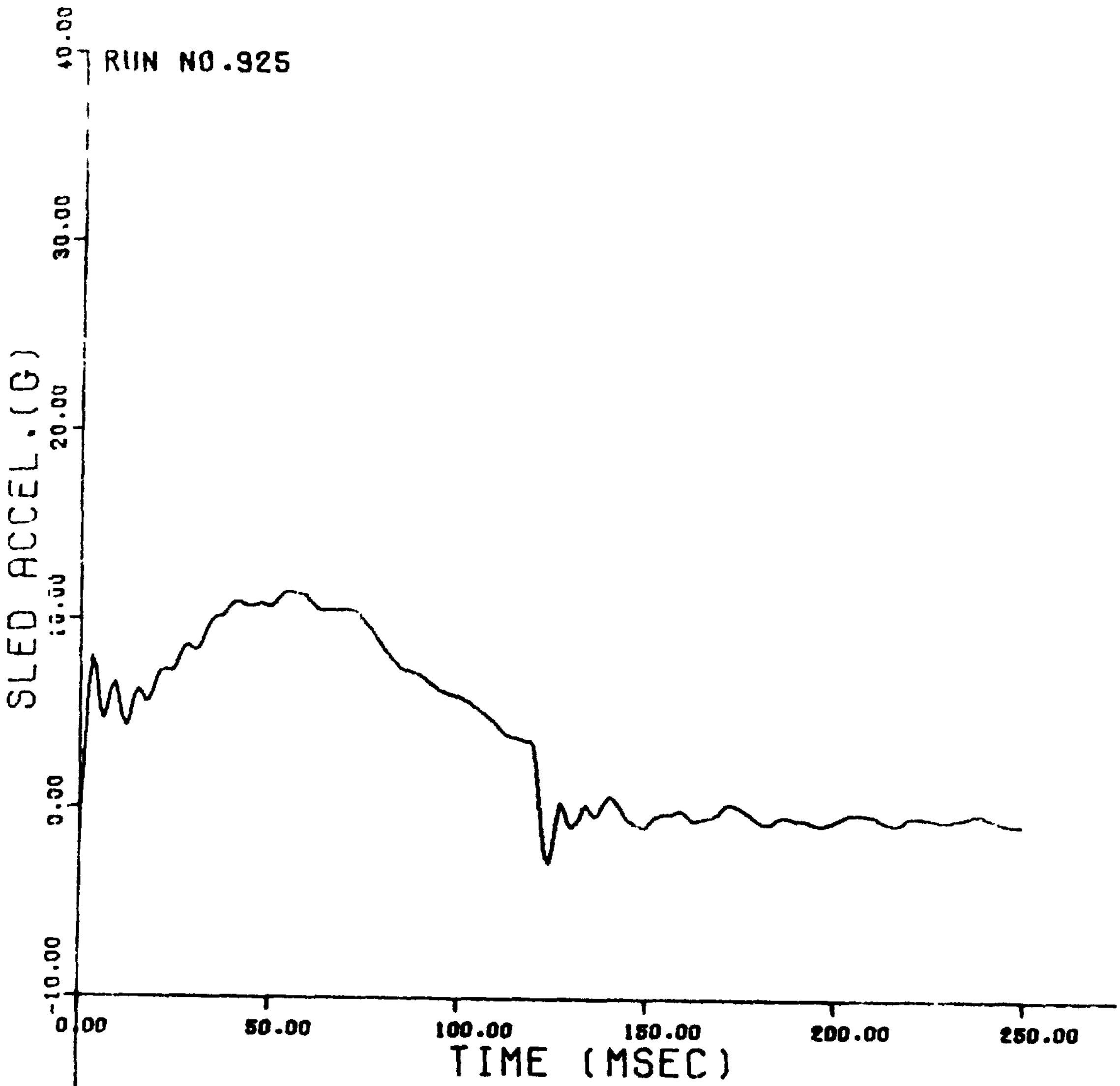
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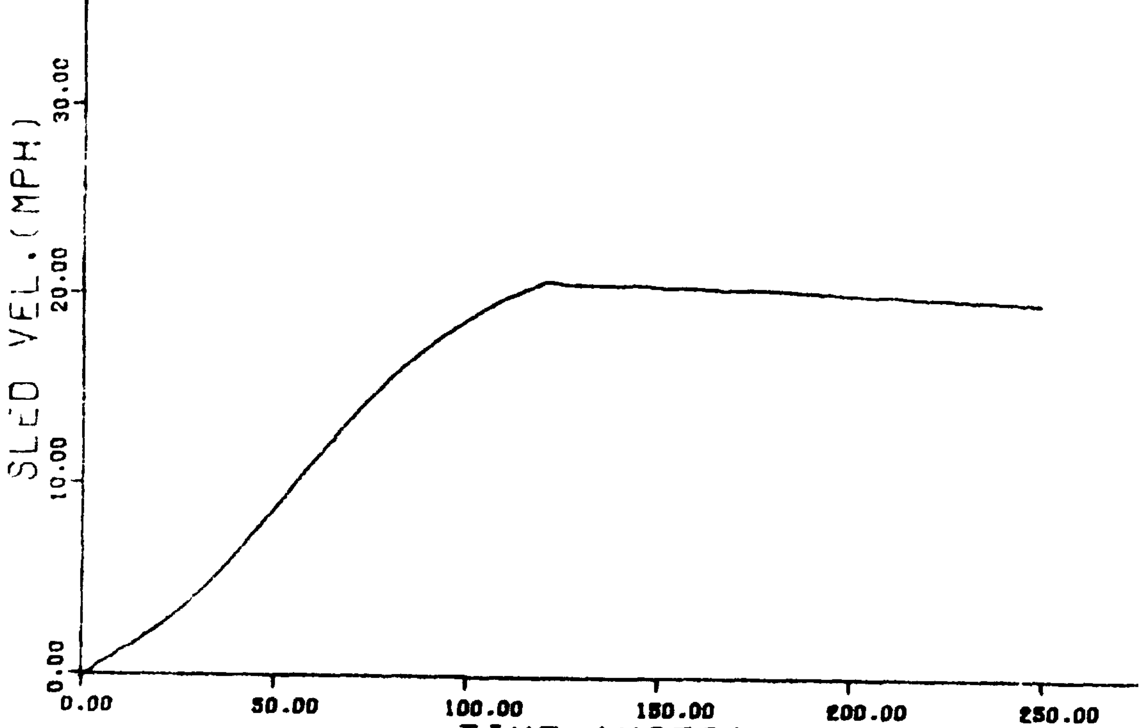
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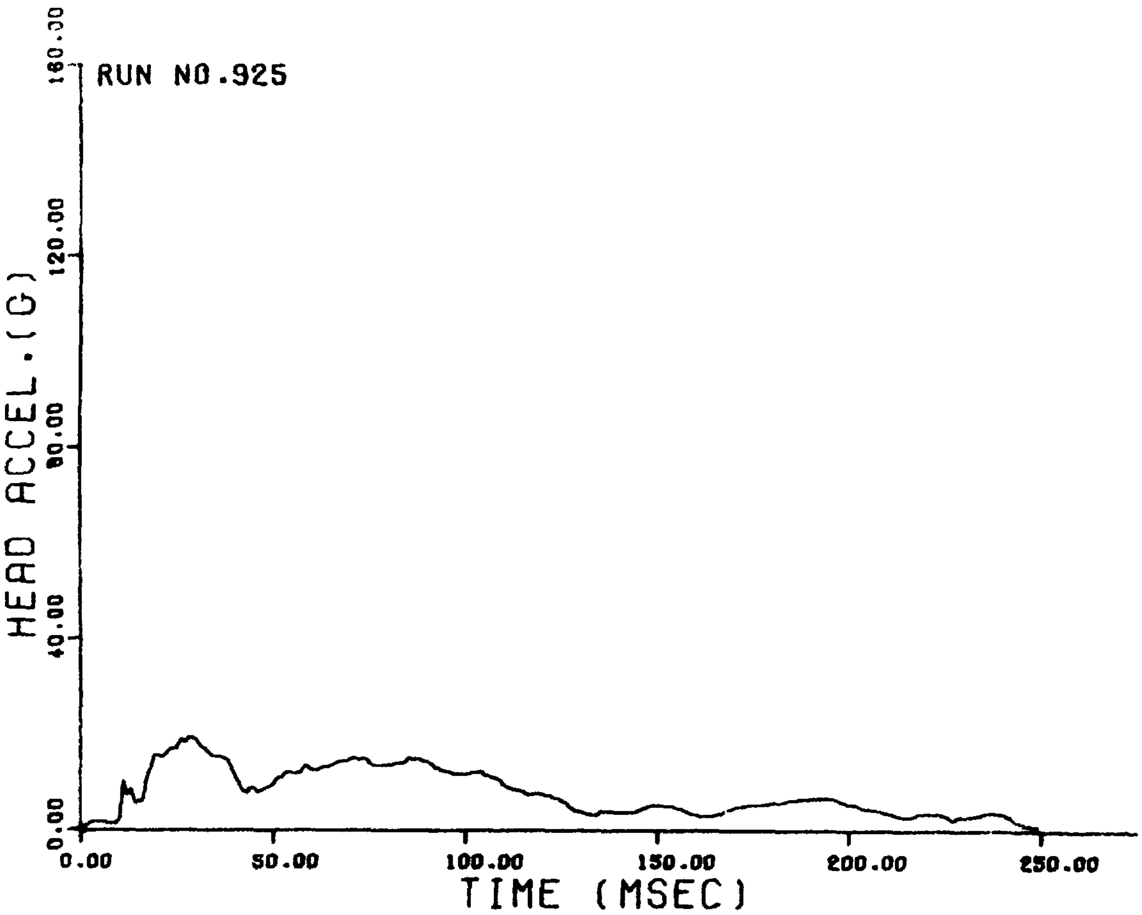
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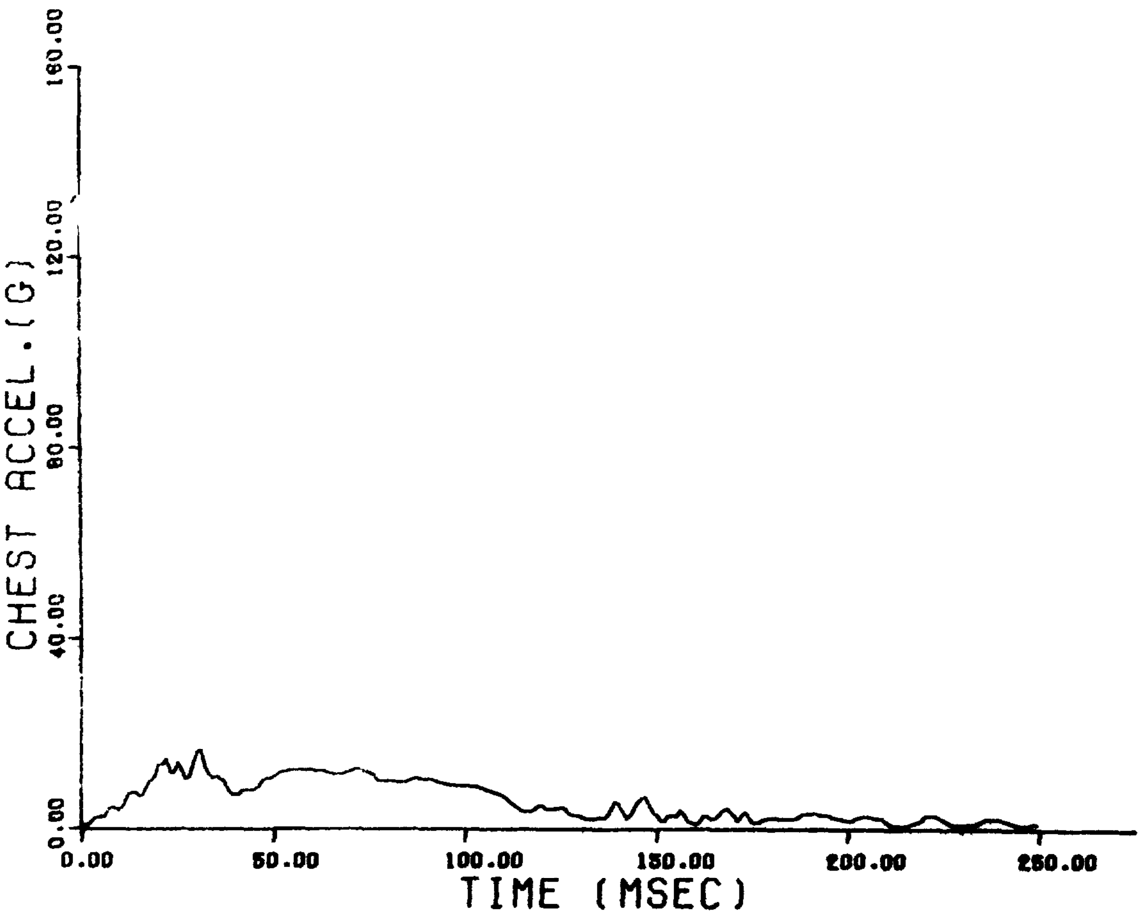
TIME (MSEC)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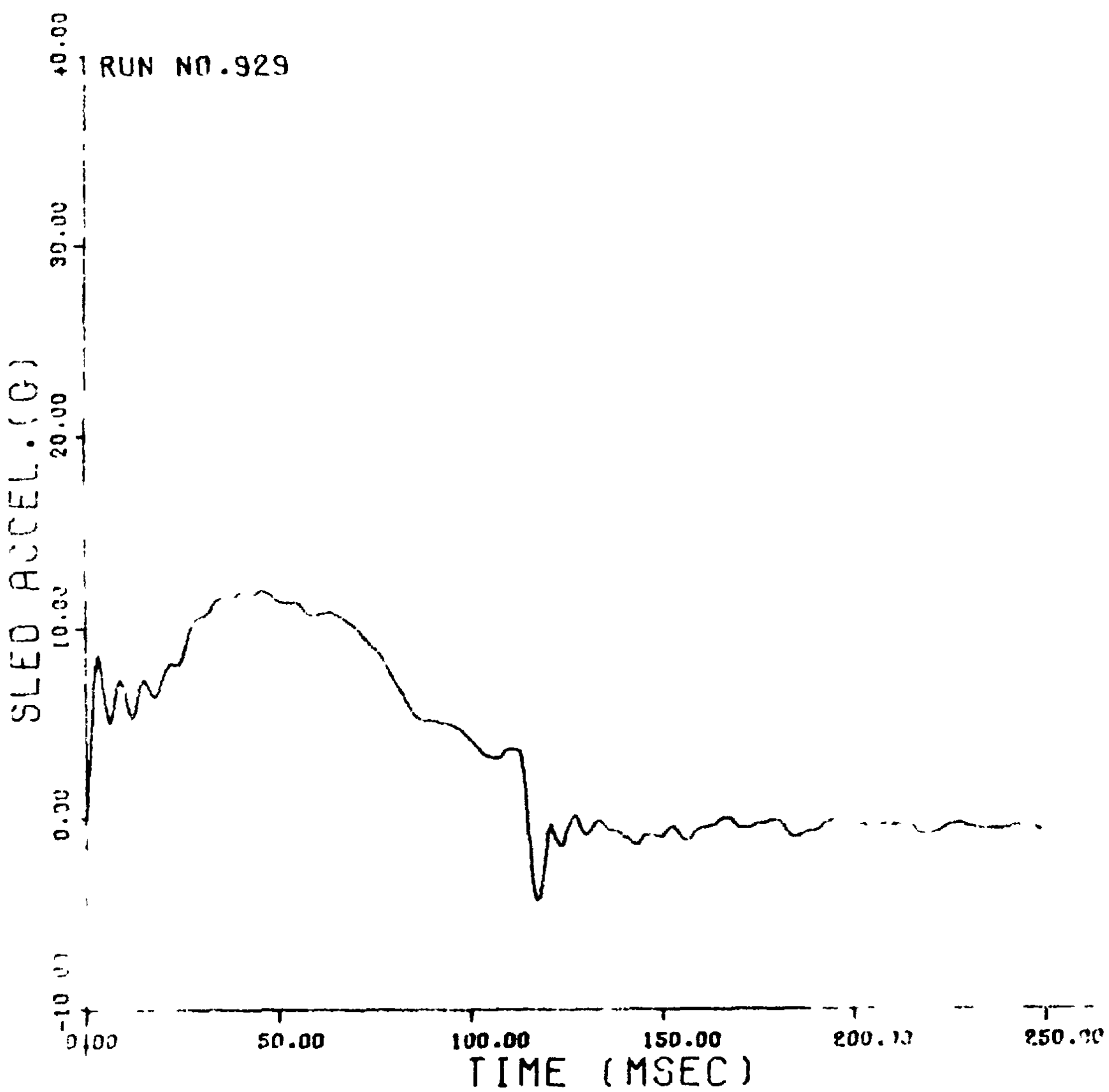
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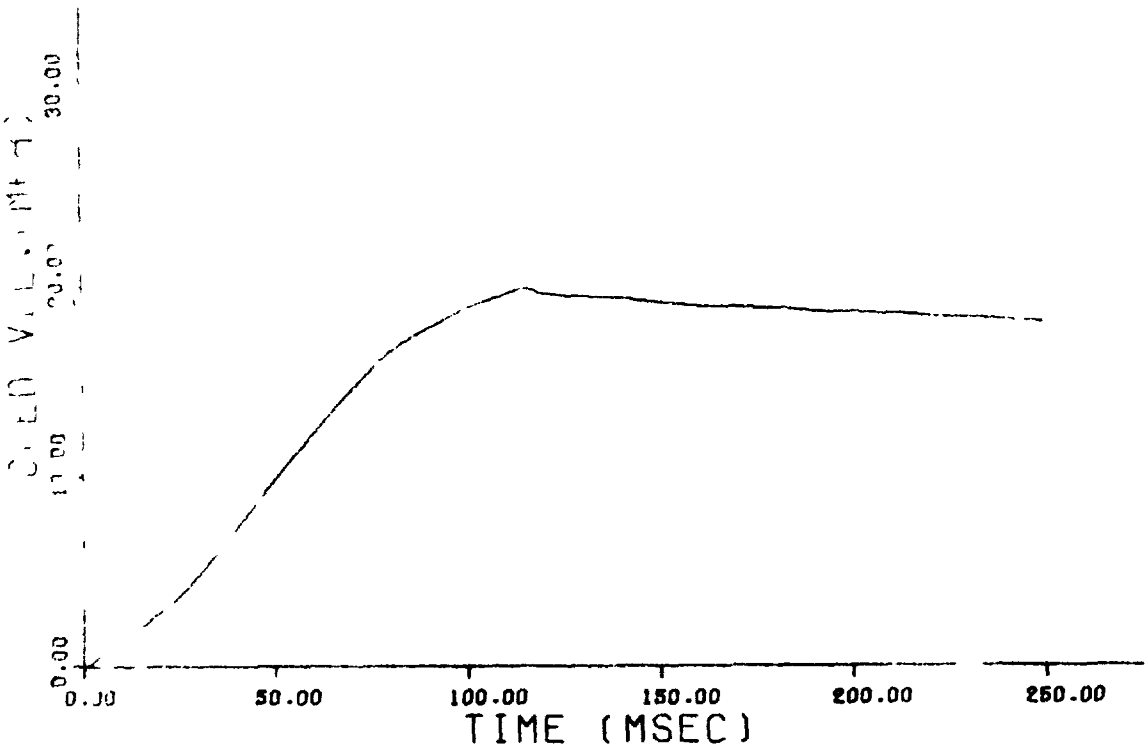
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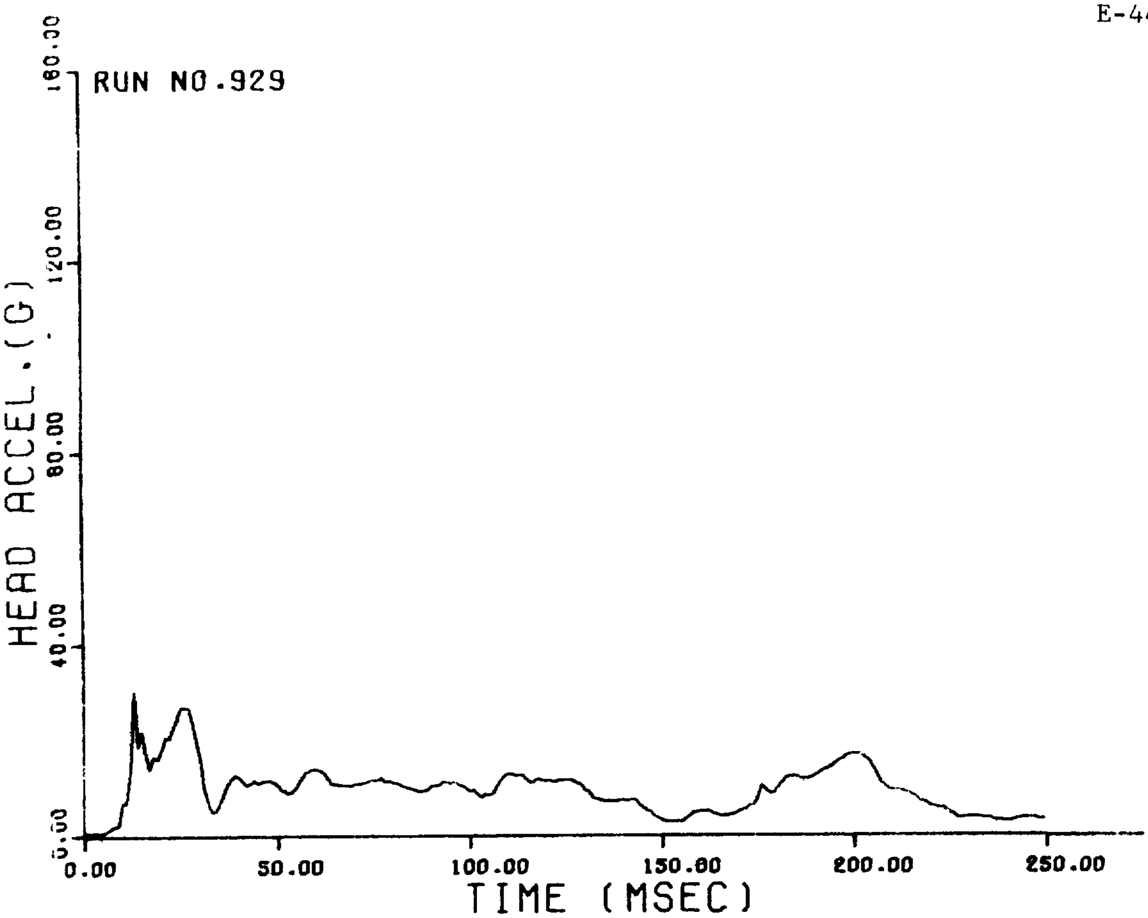
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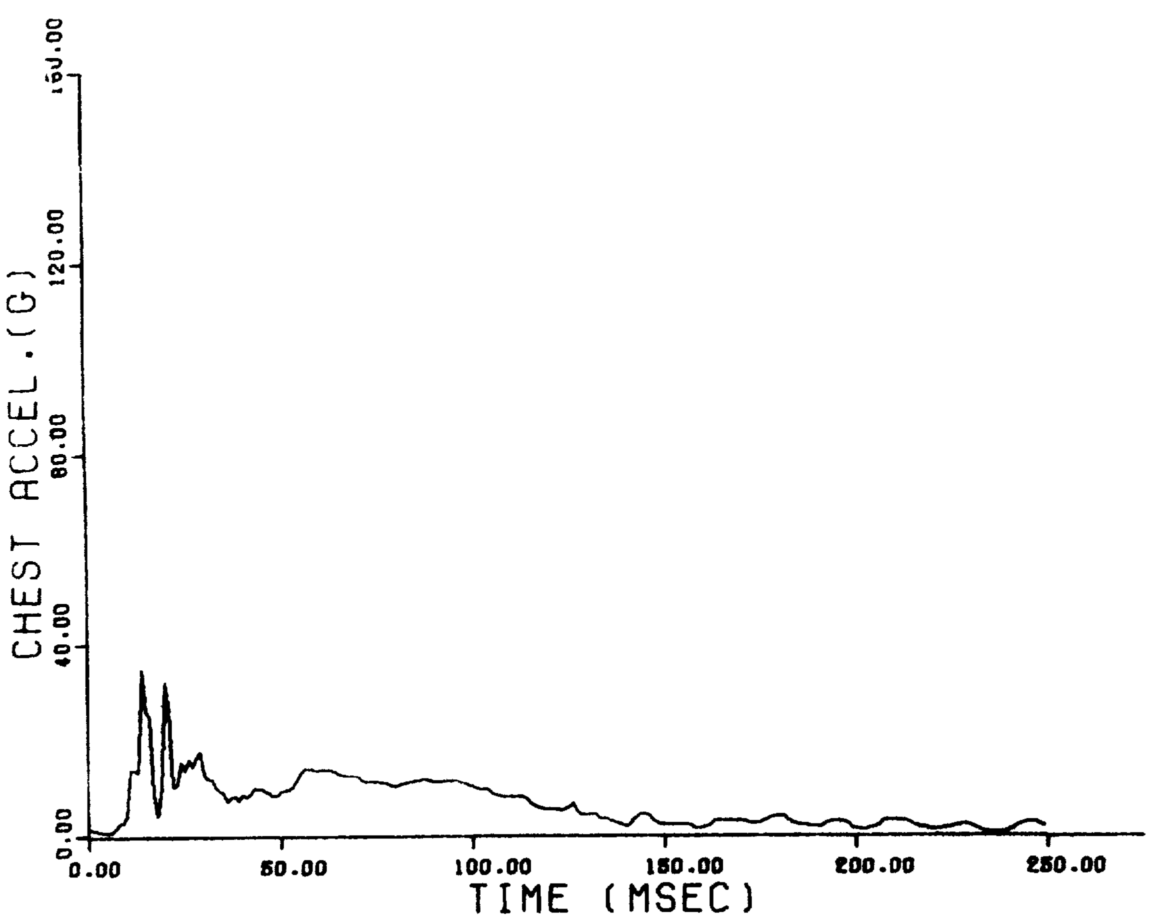
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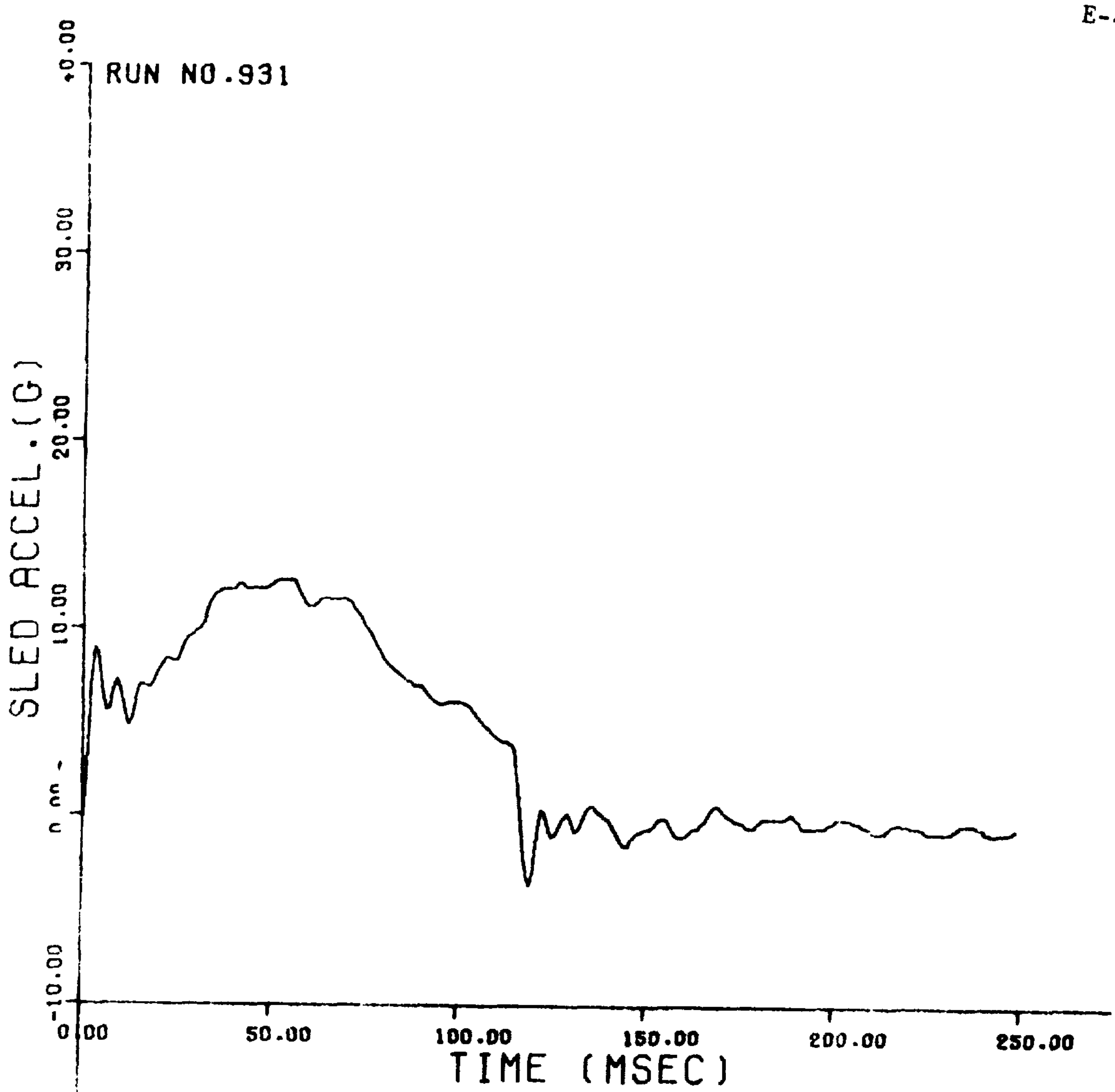
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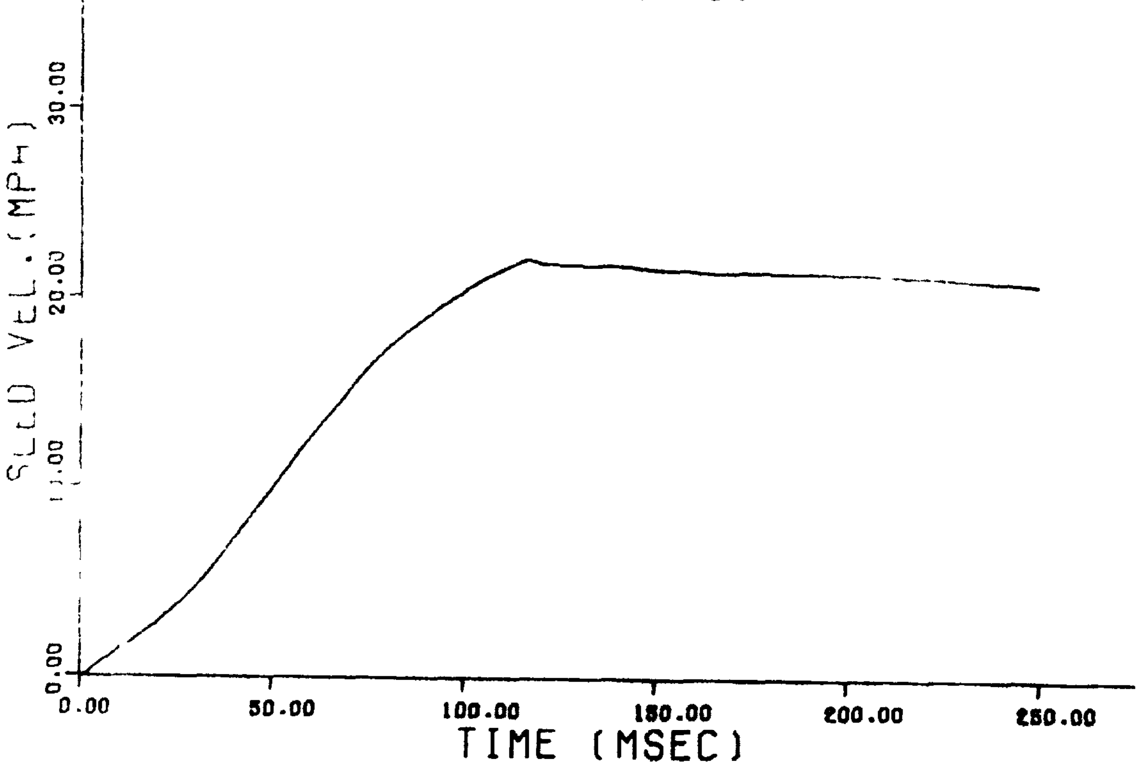
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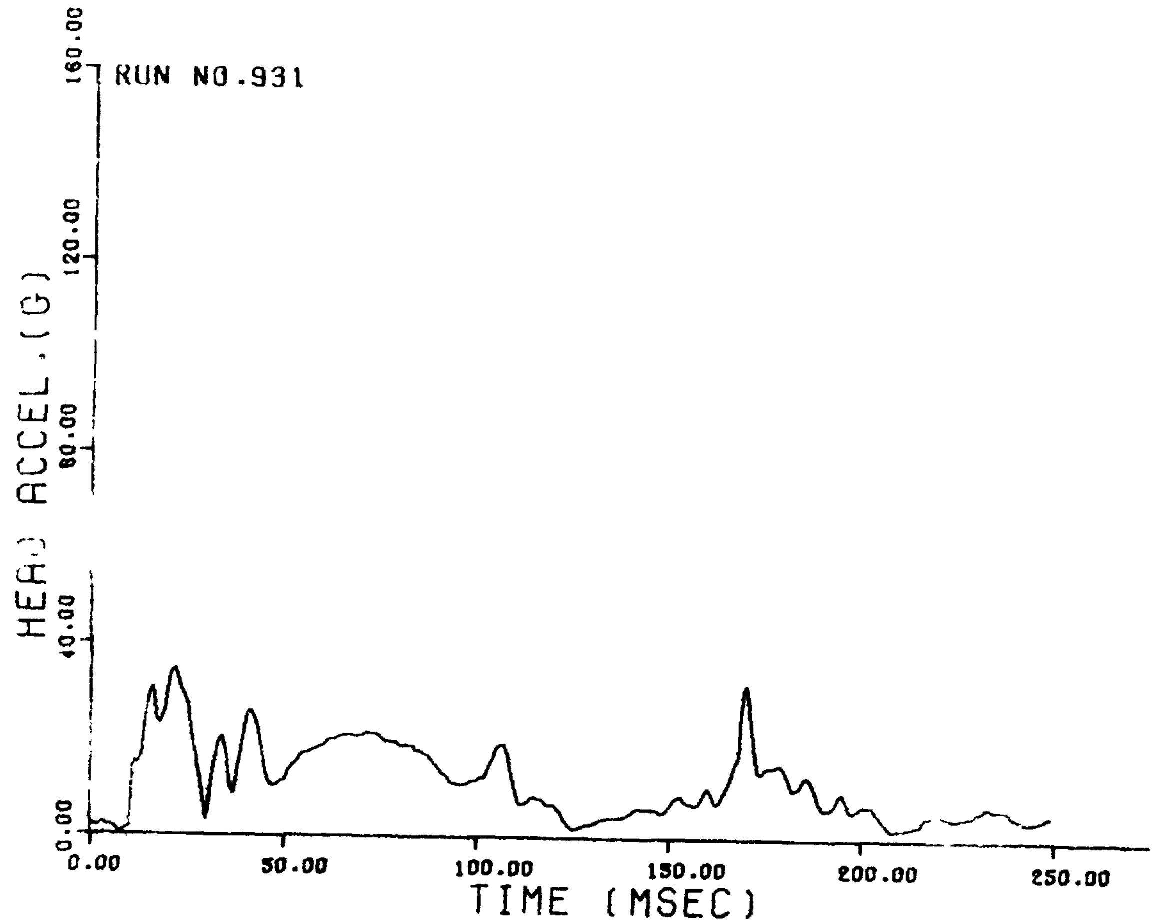
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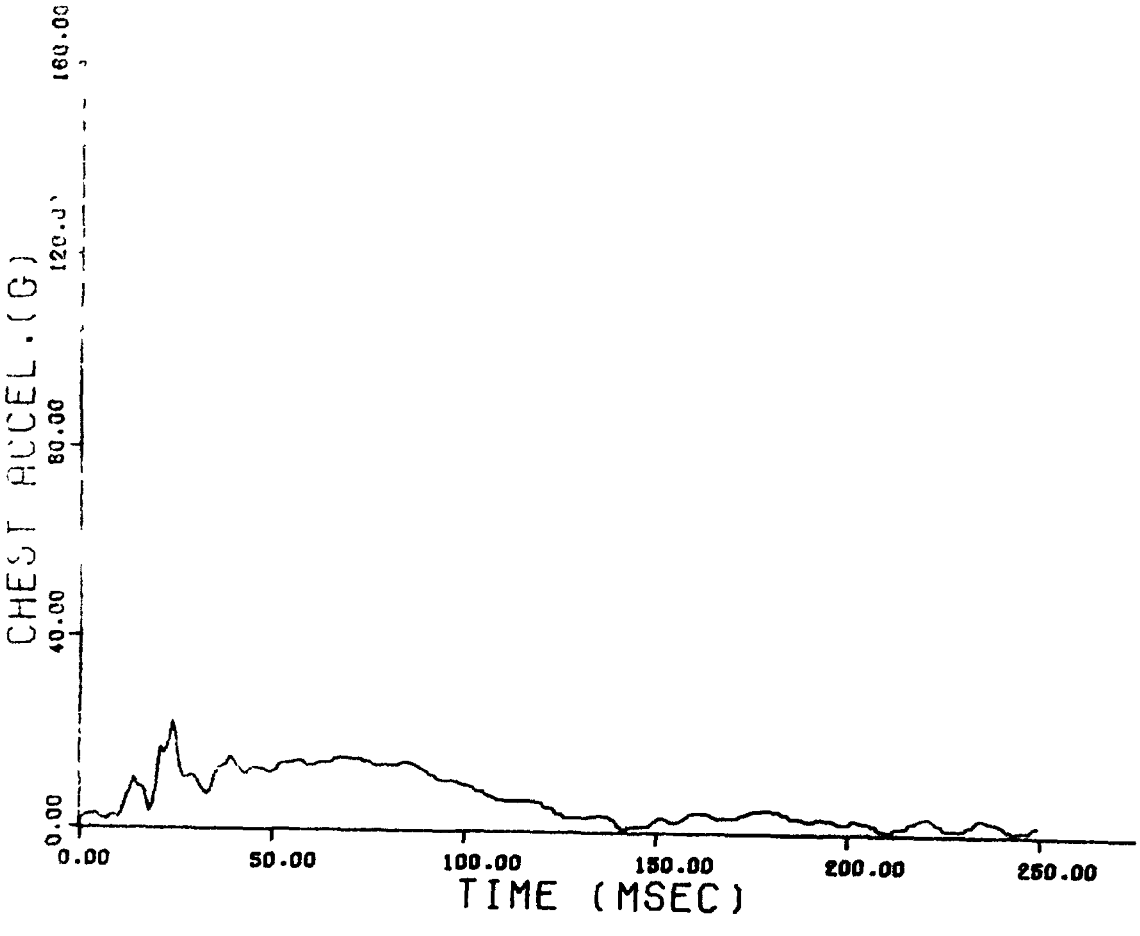
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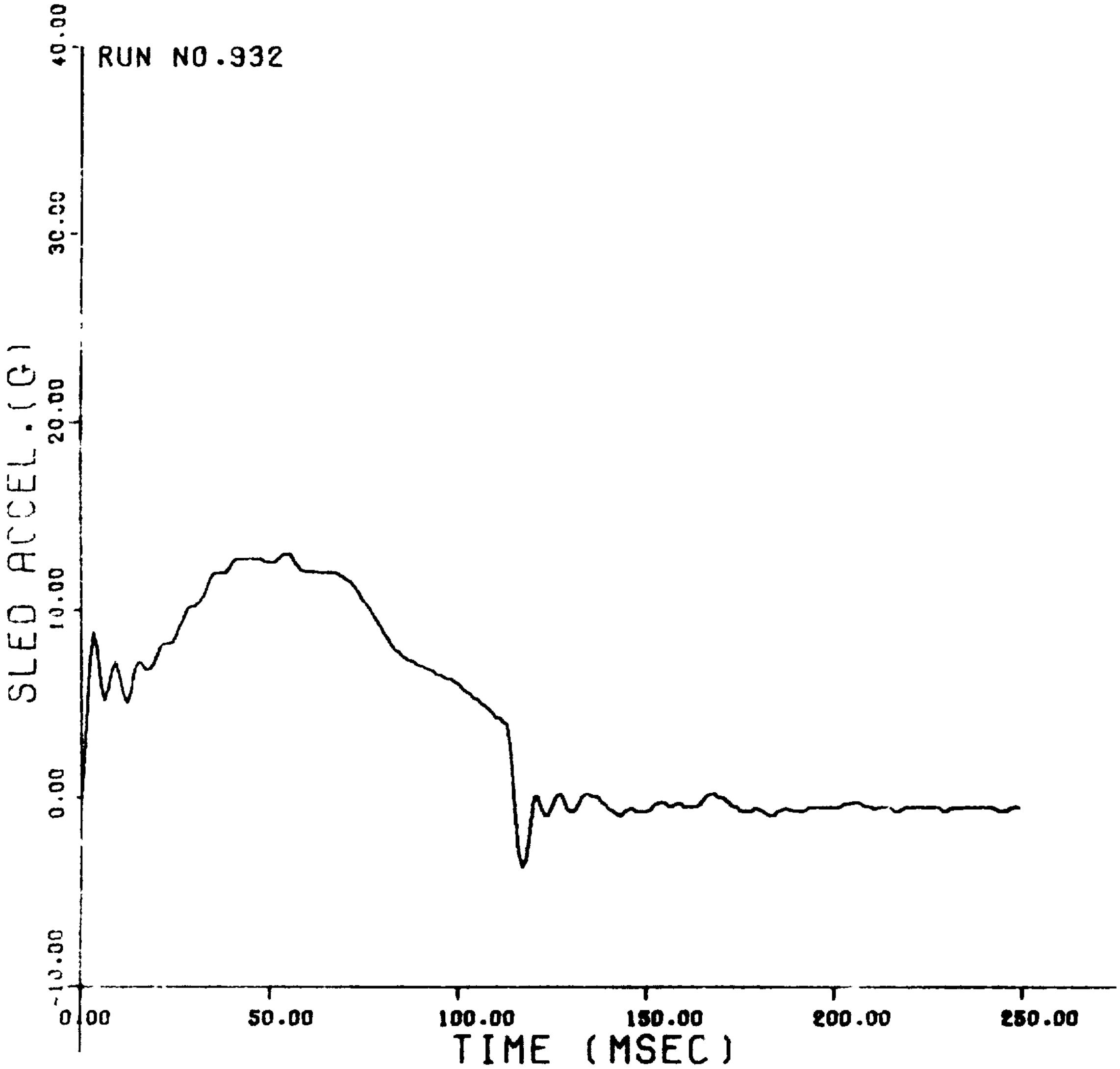
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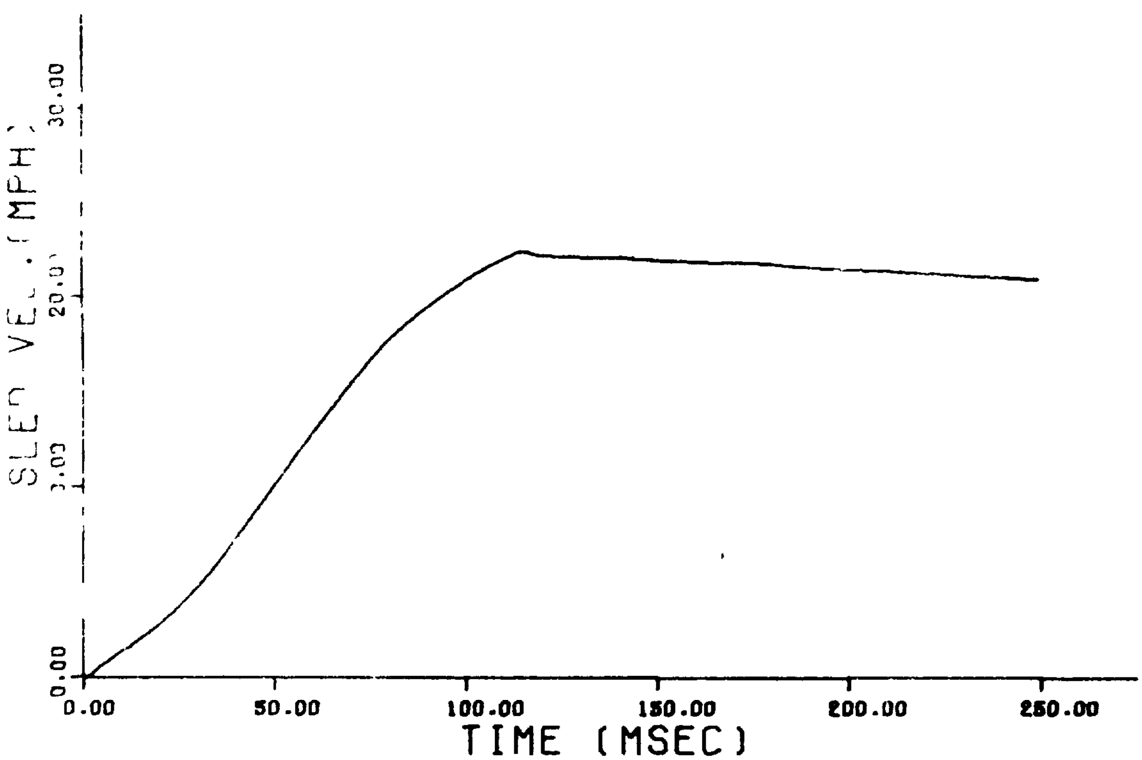
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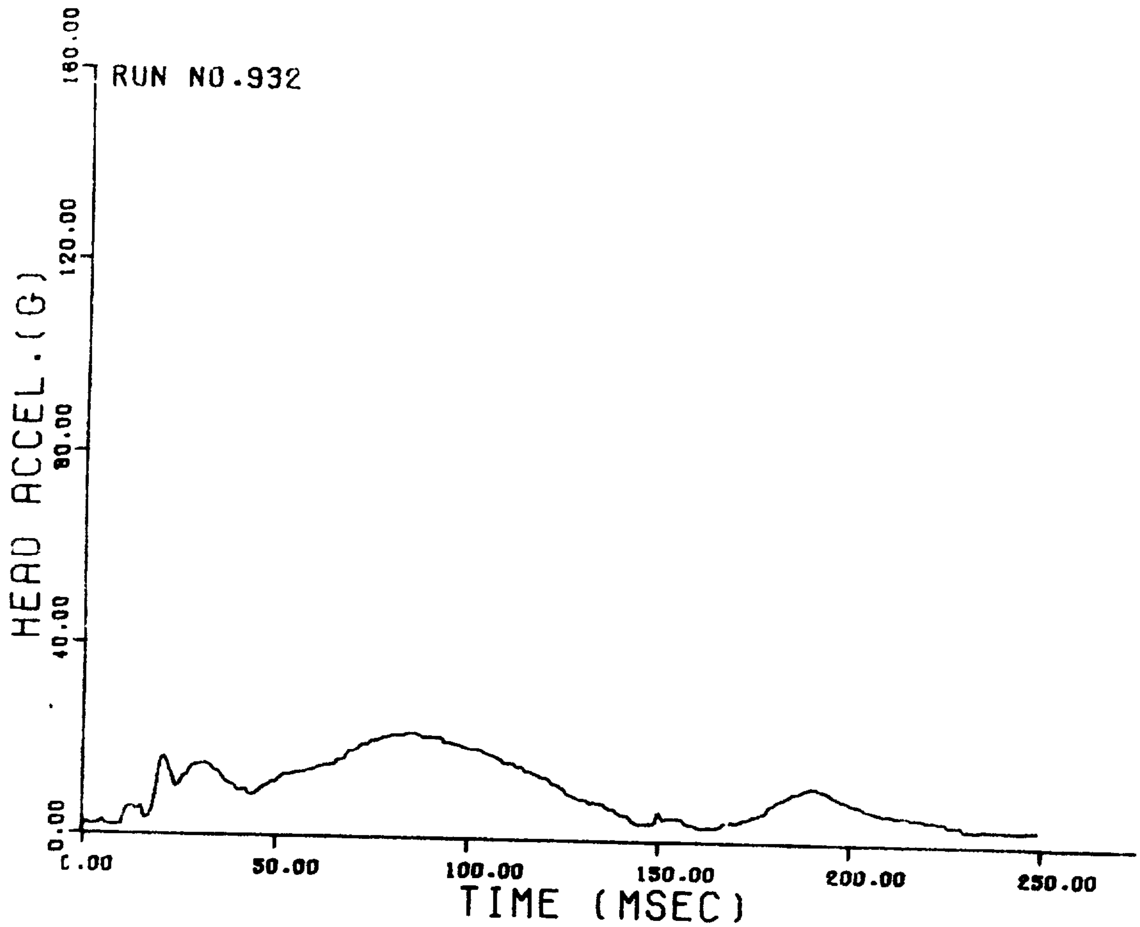
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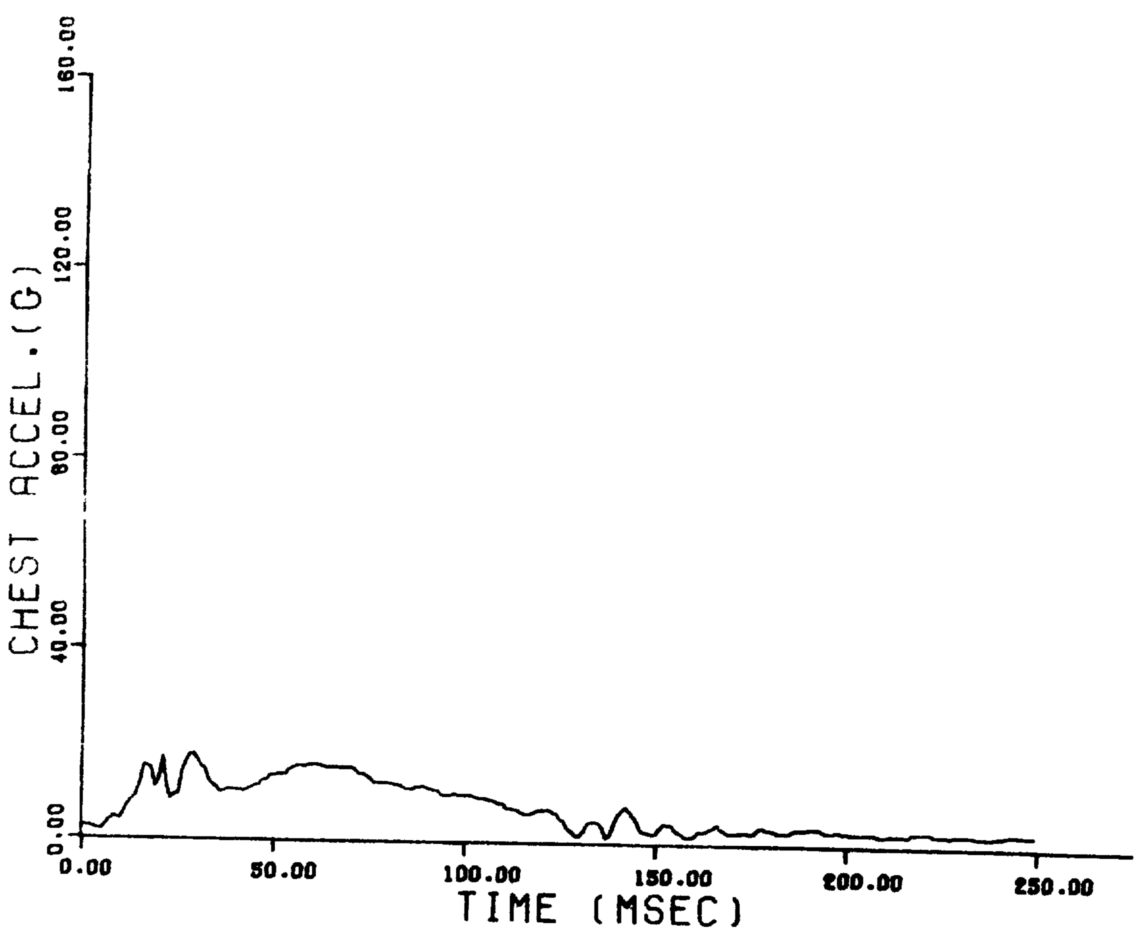
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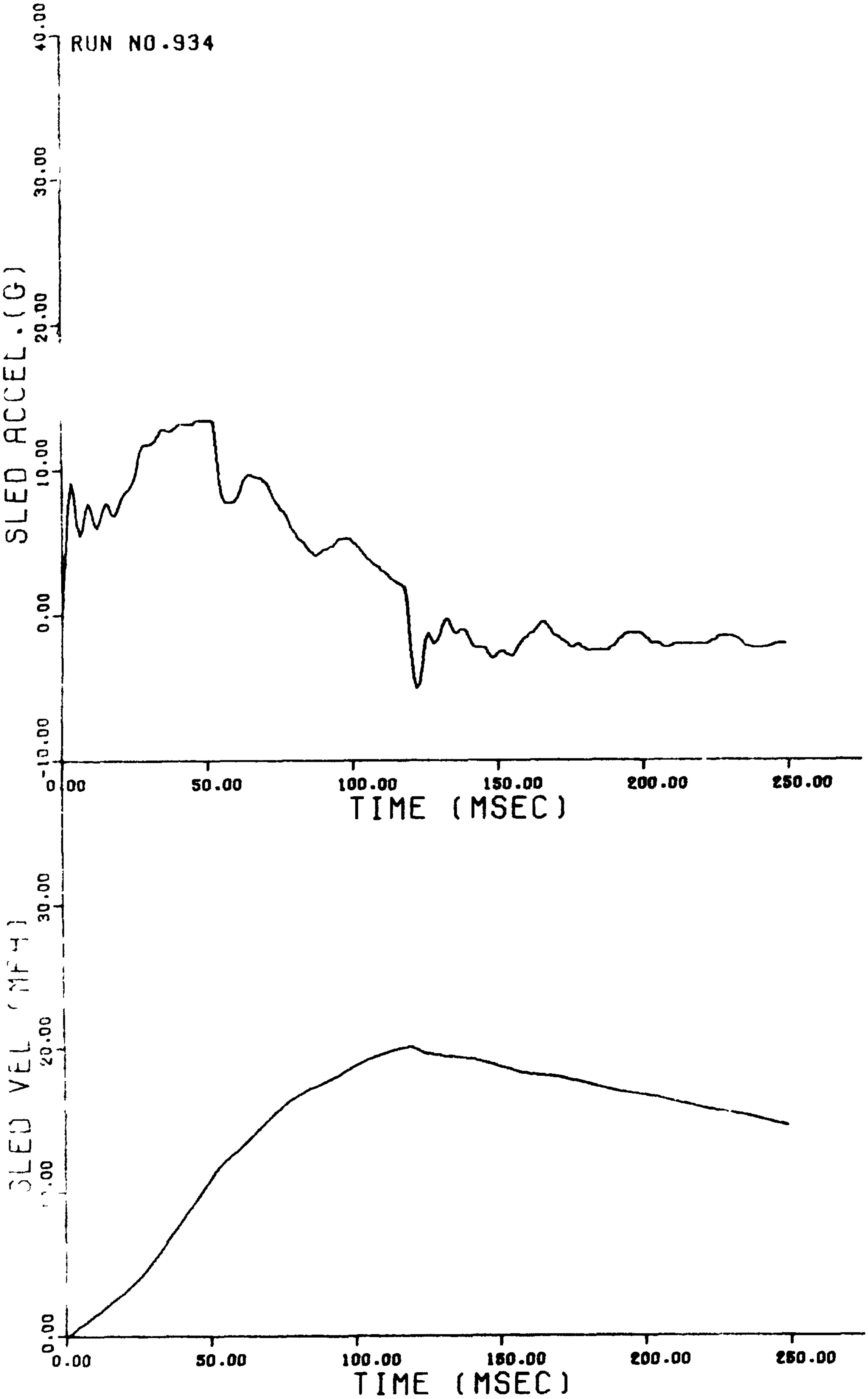
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TIME (MSEC)
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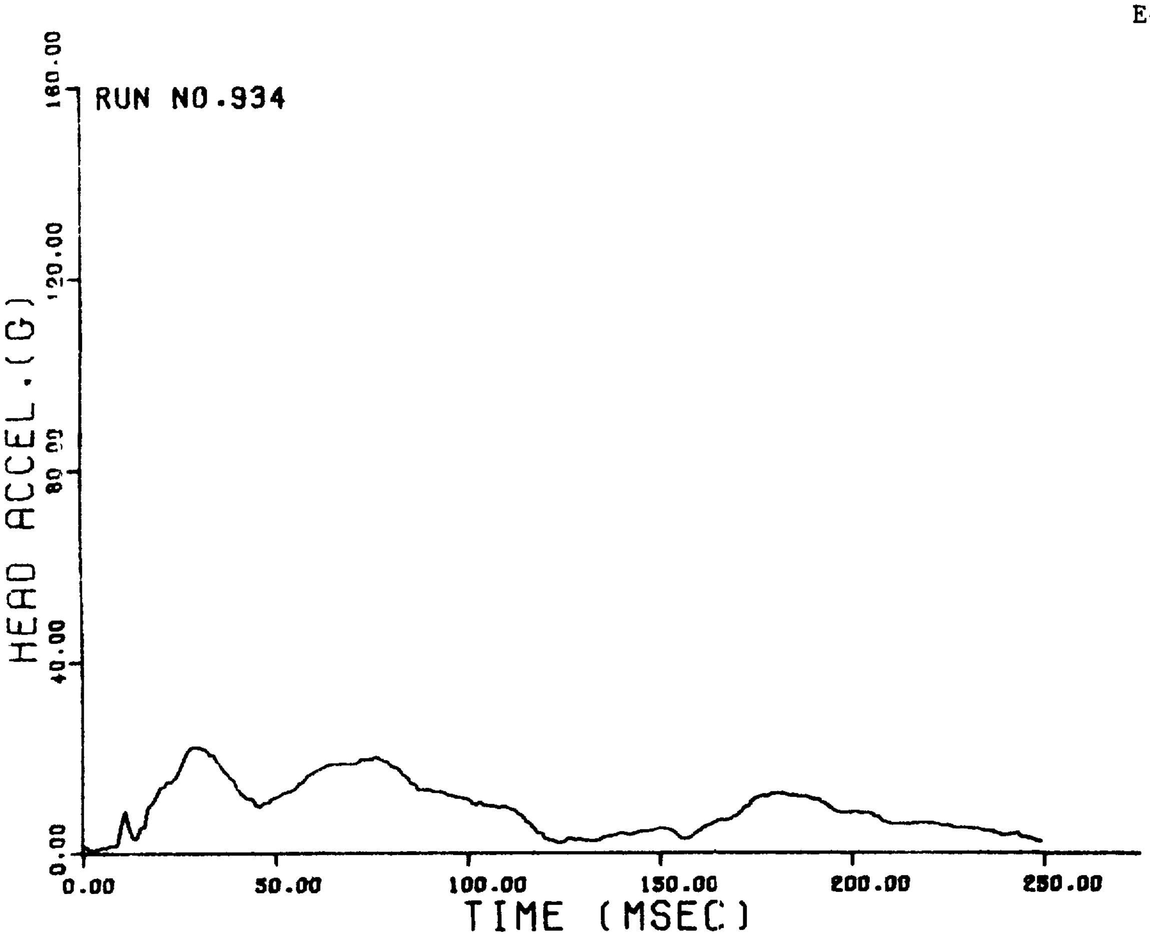
TIME (MSEC)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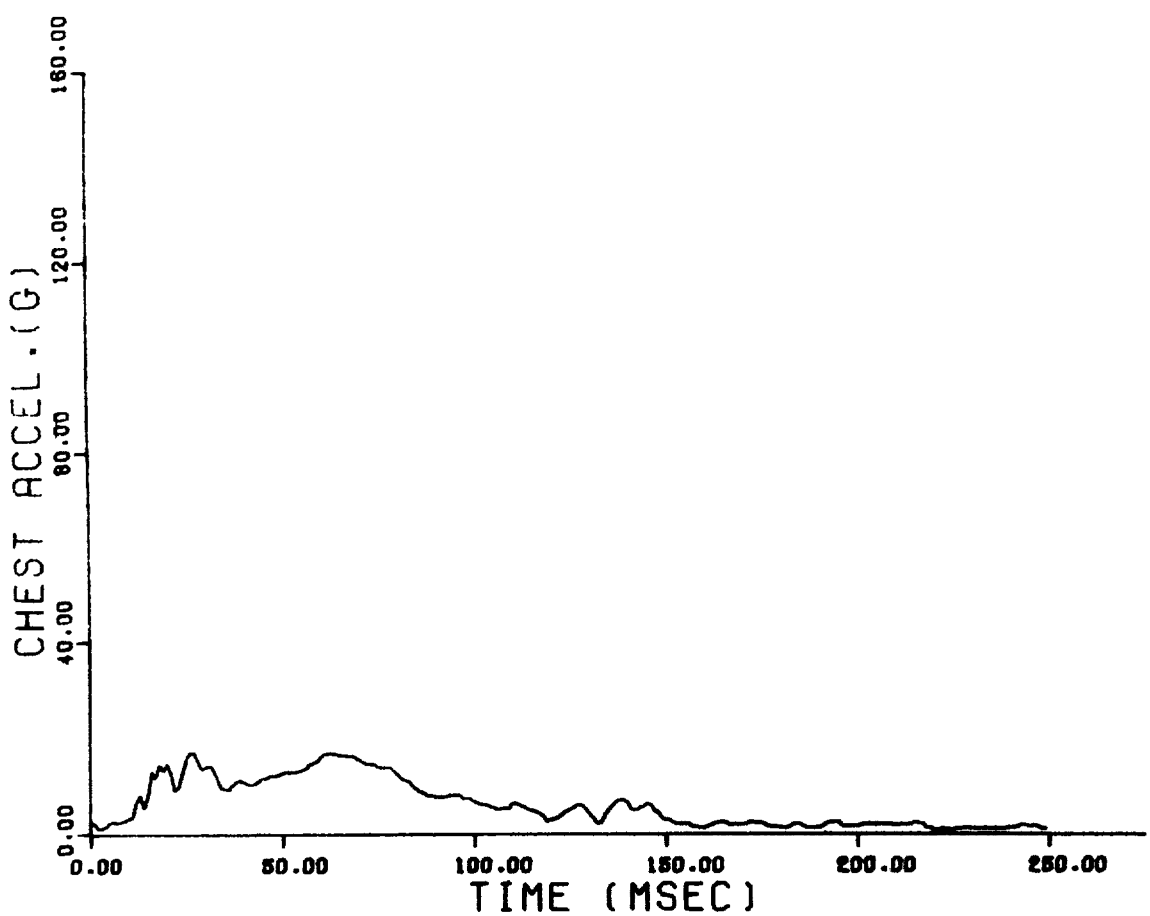
TIME (MSEC)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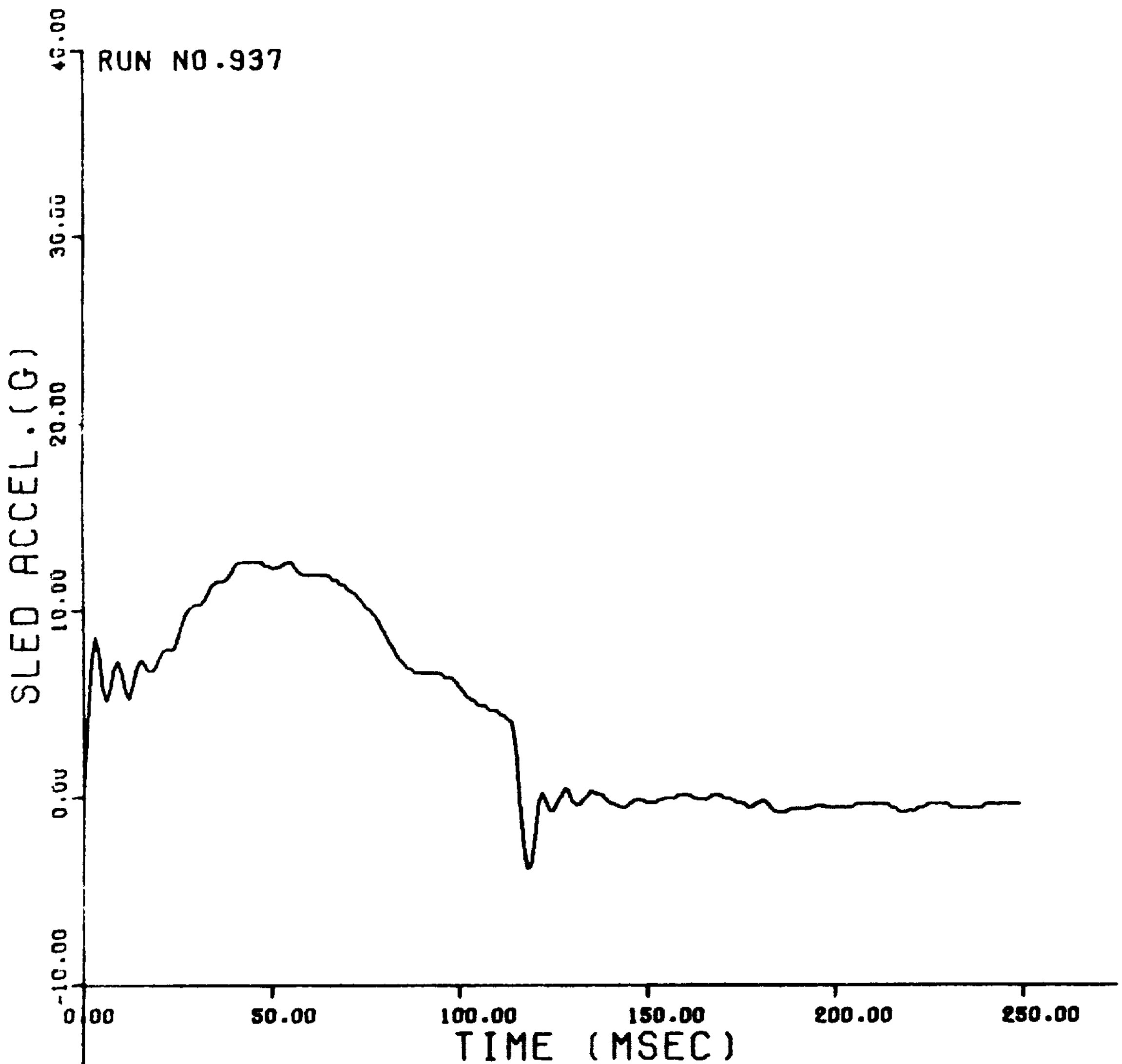
TIME (MSEC)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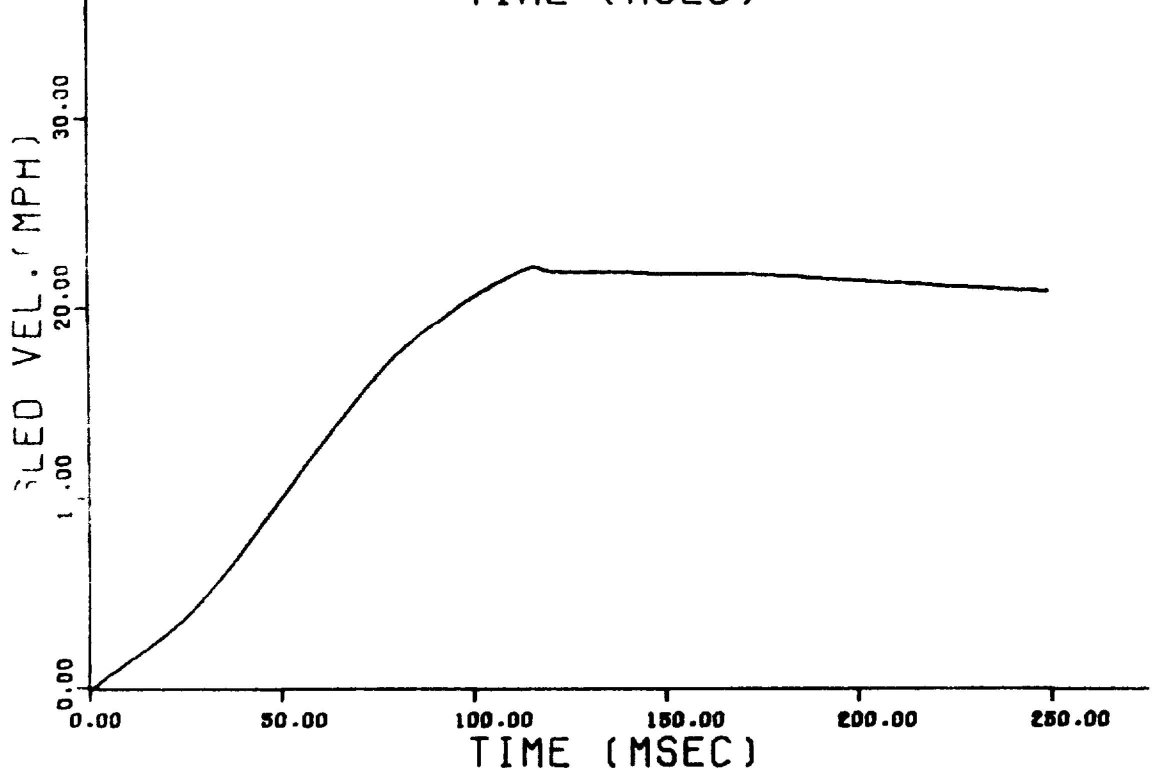
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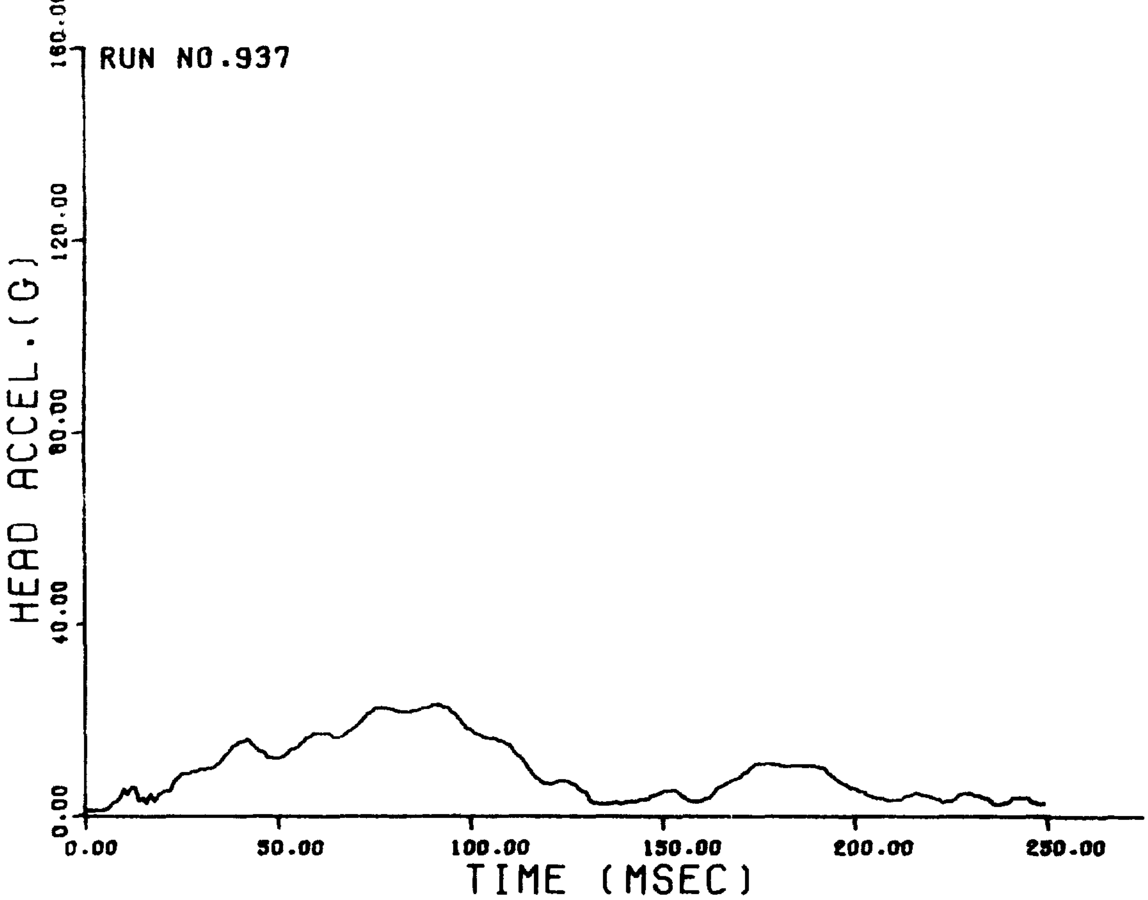
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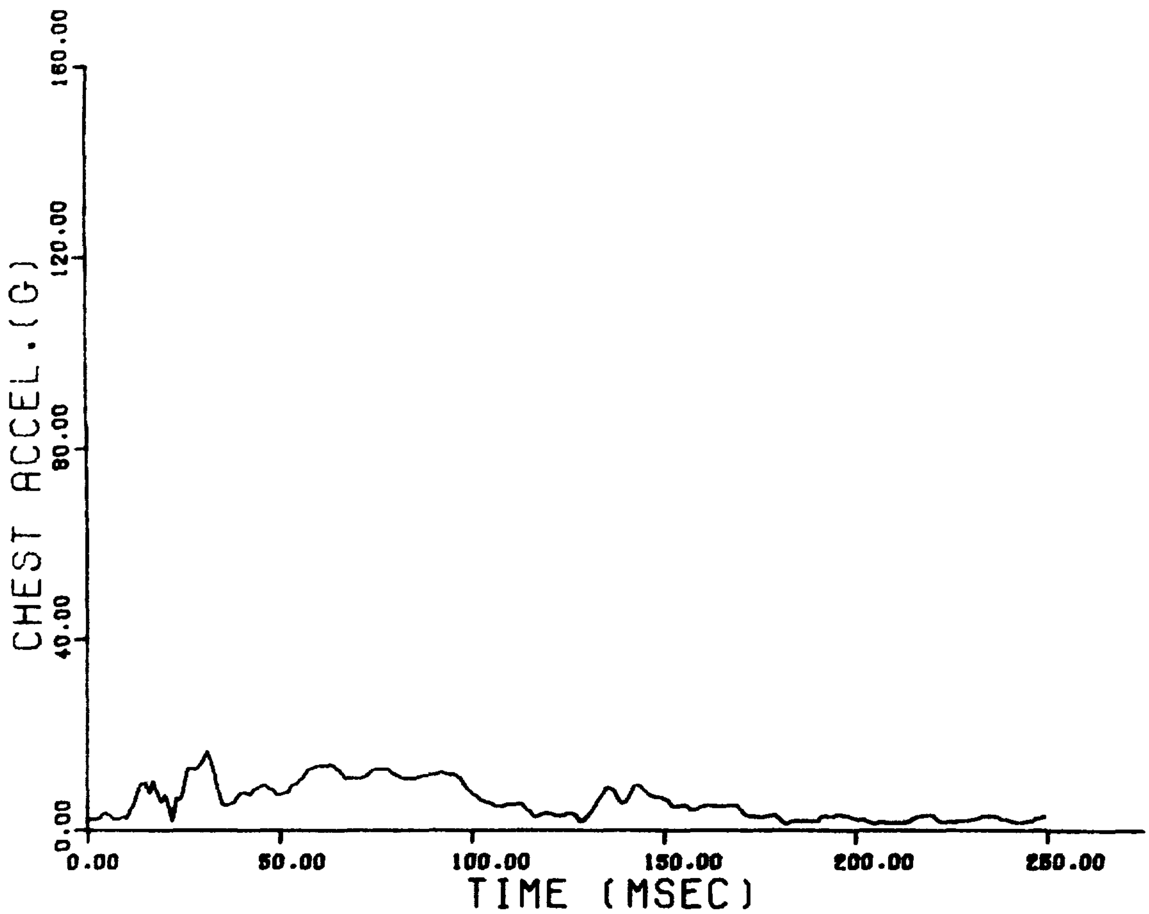
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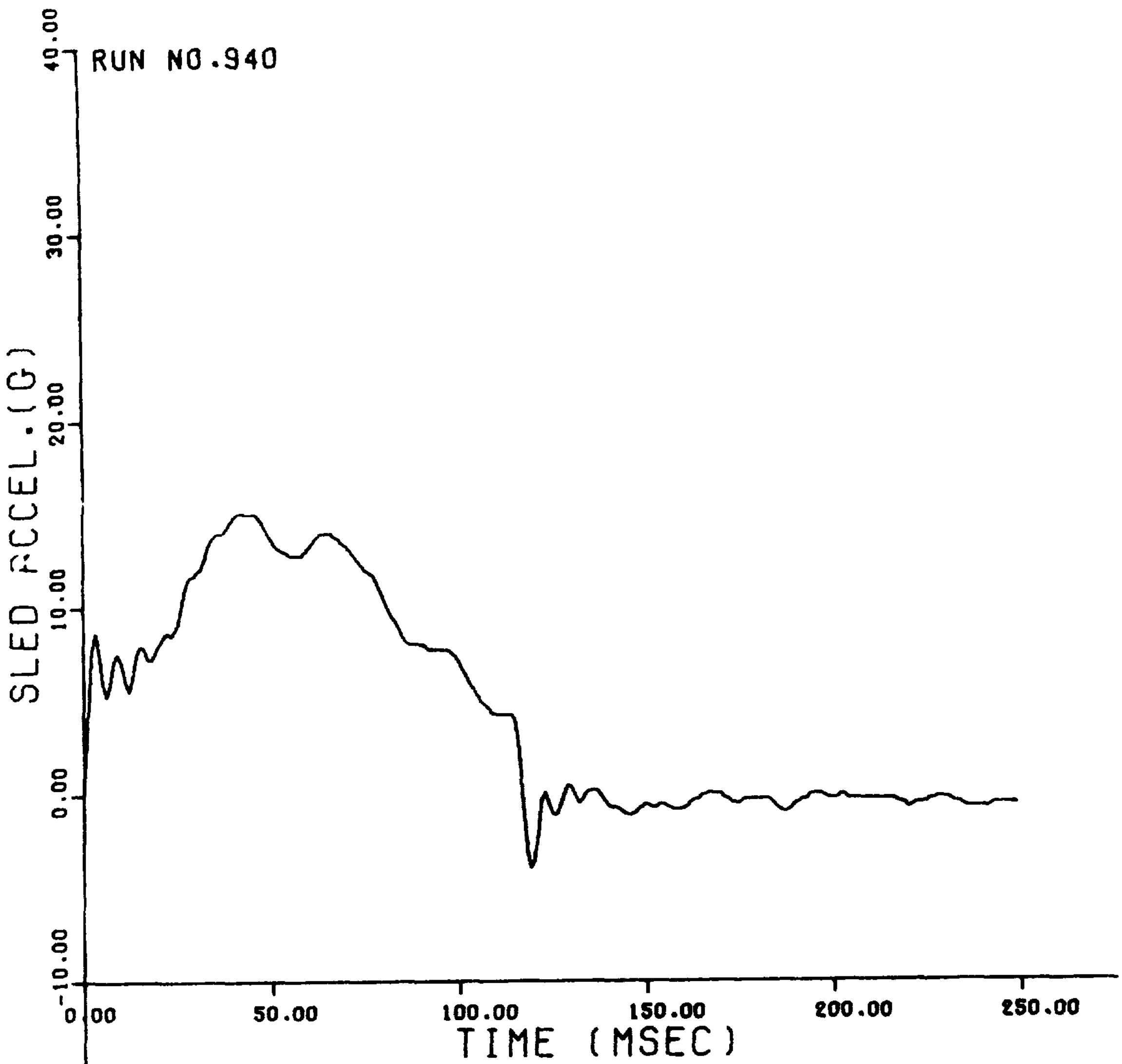
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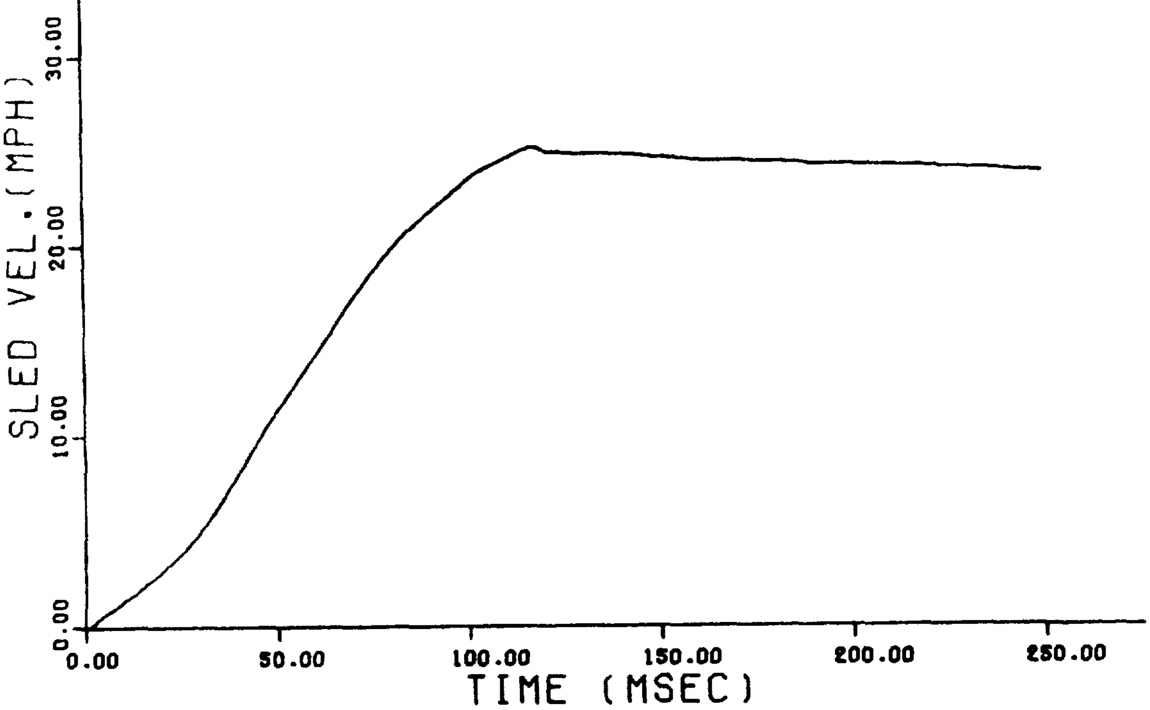
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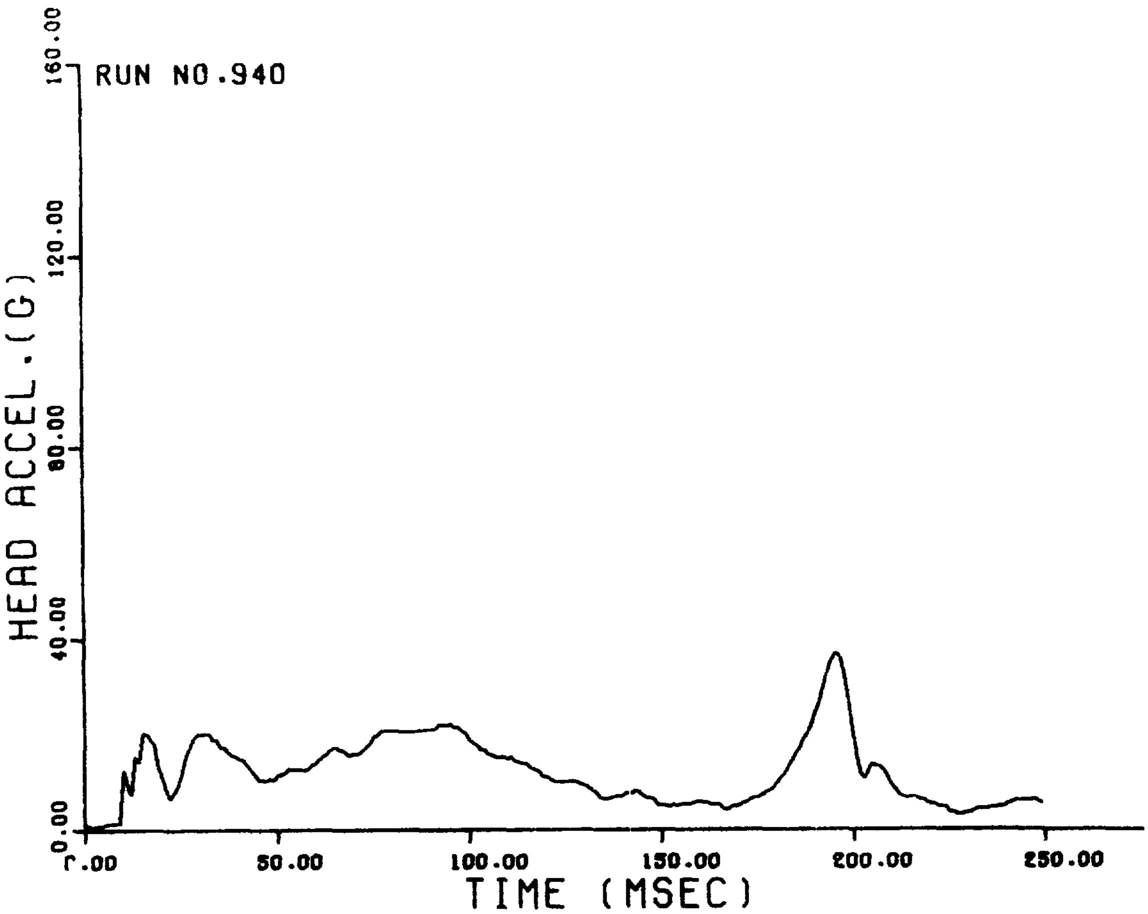
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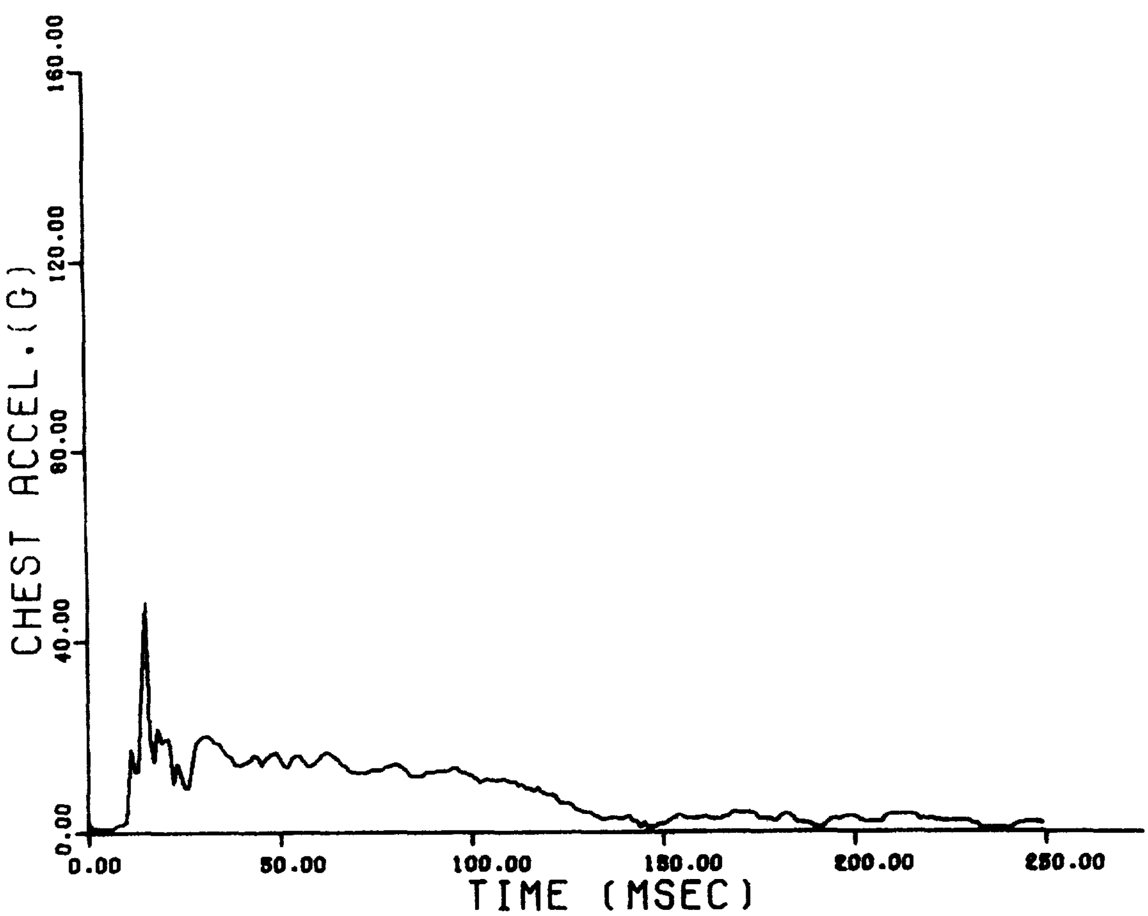
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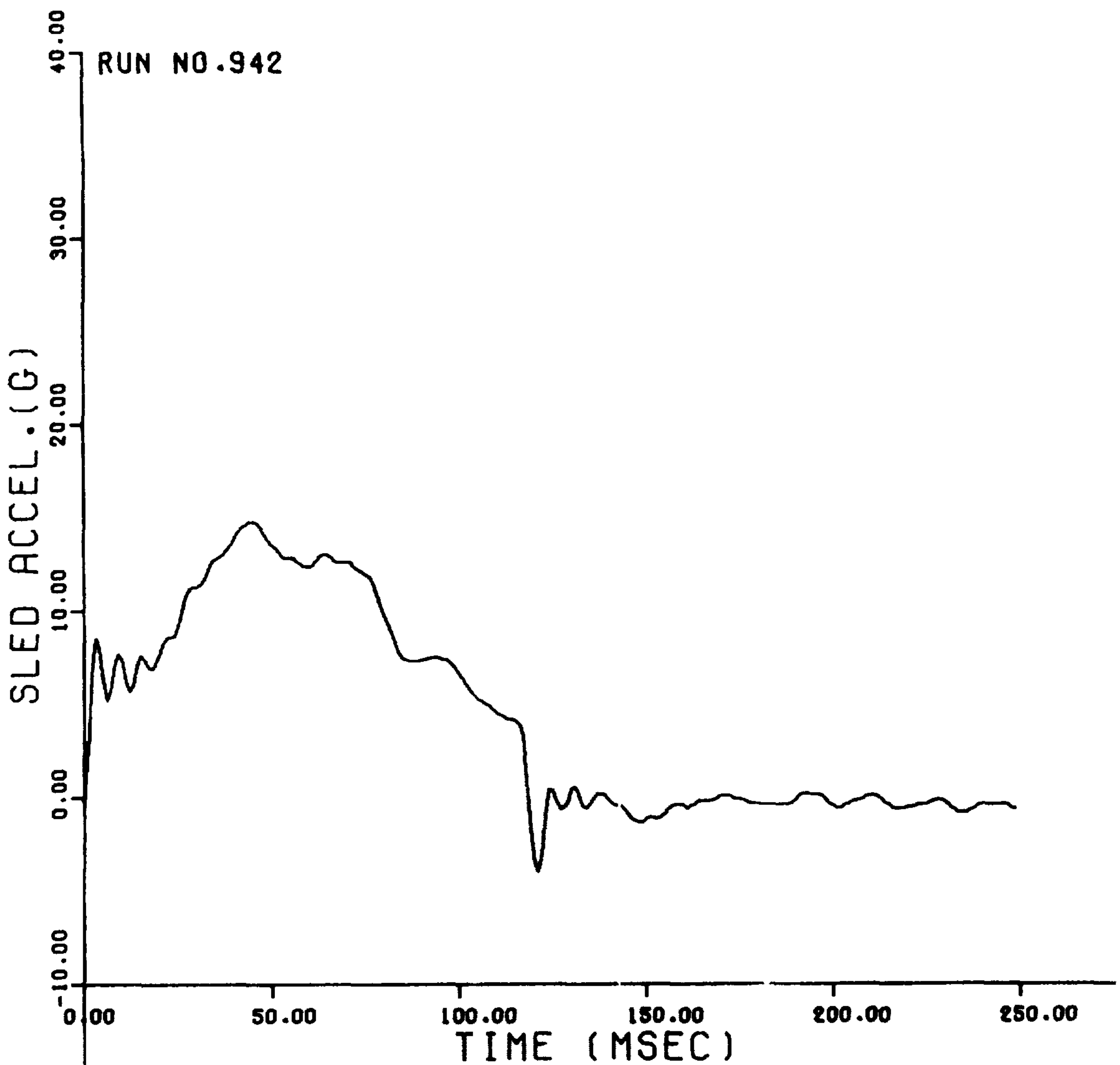
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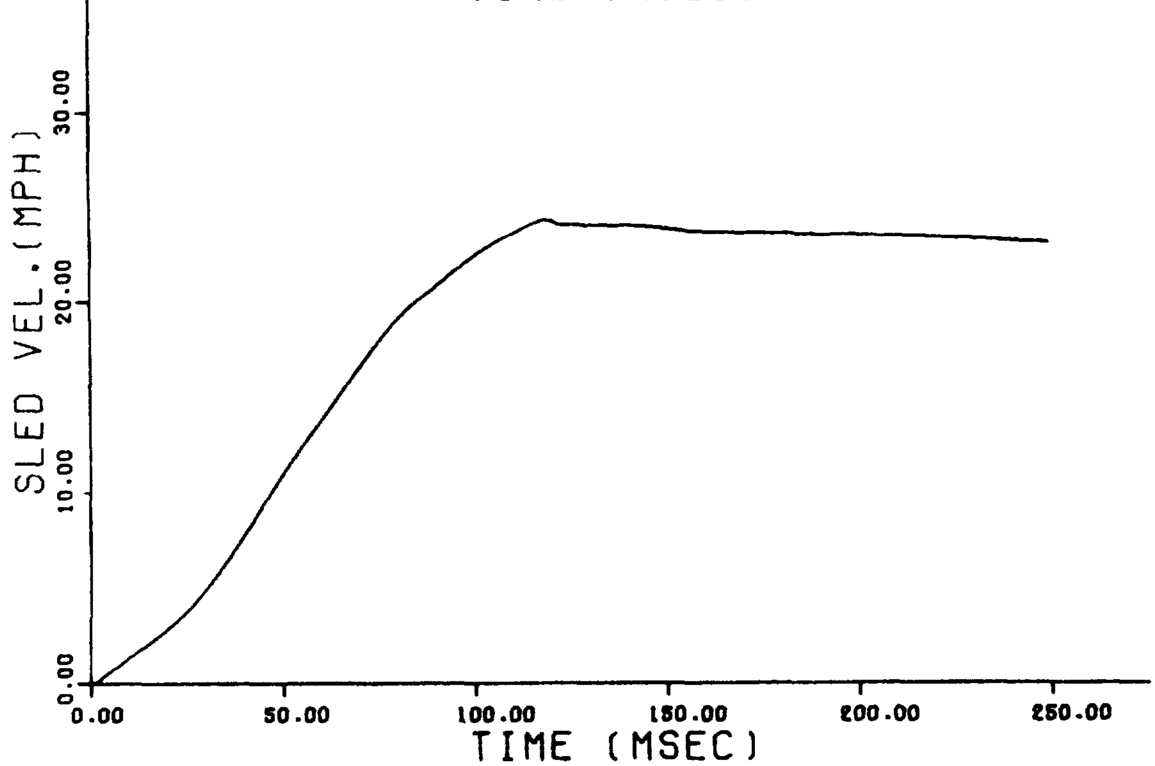
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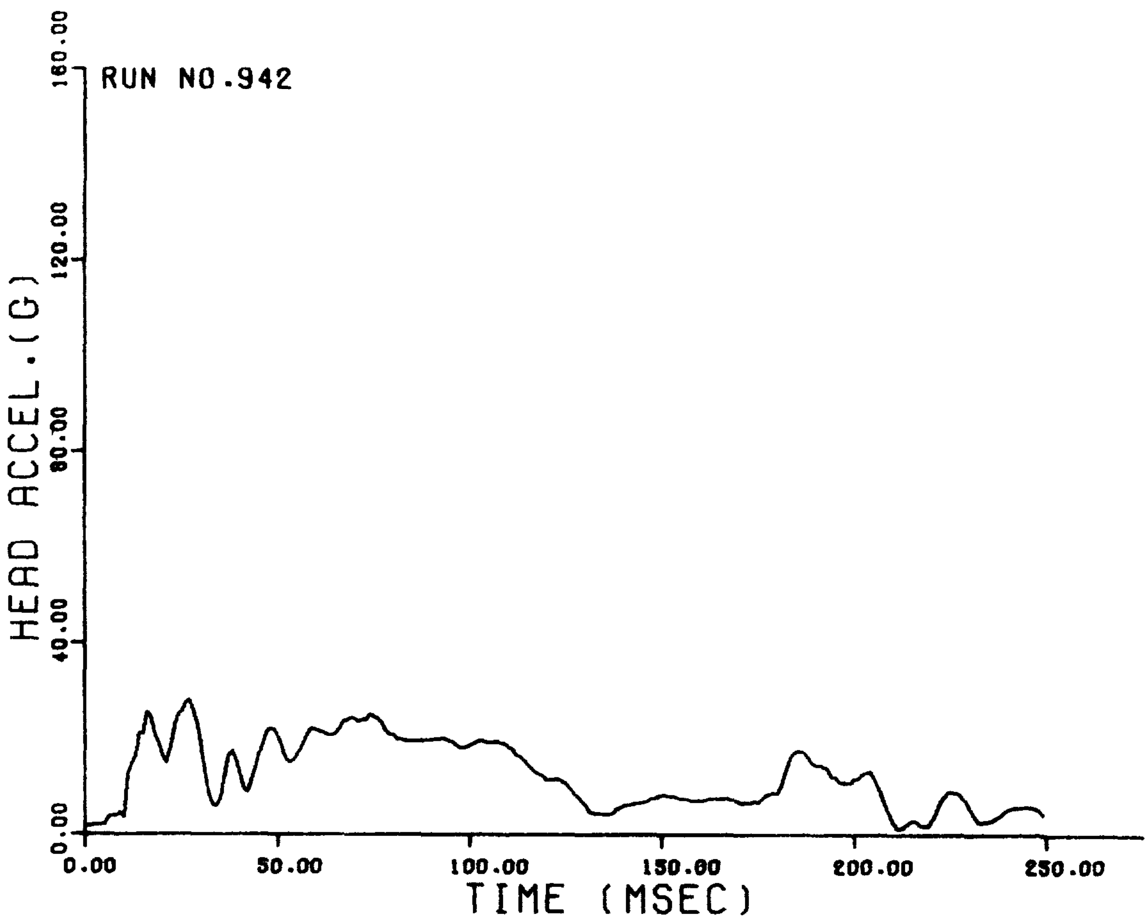
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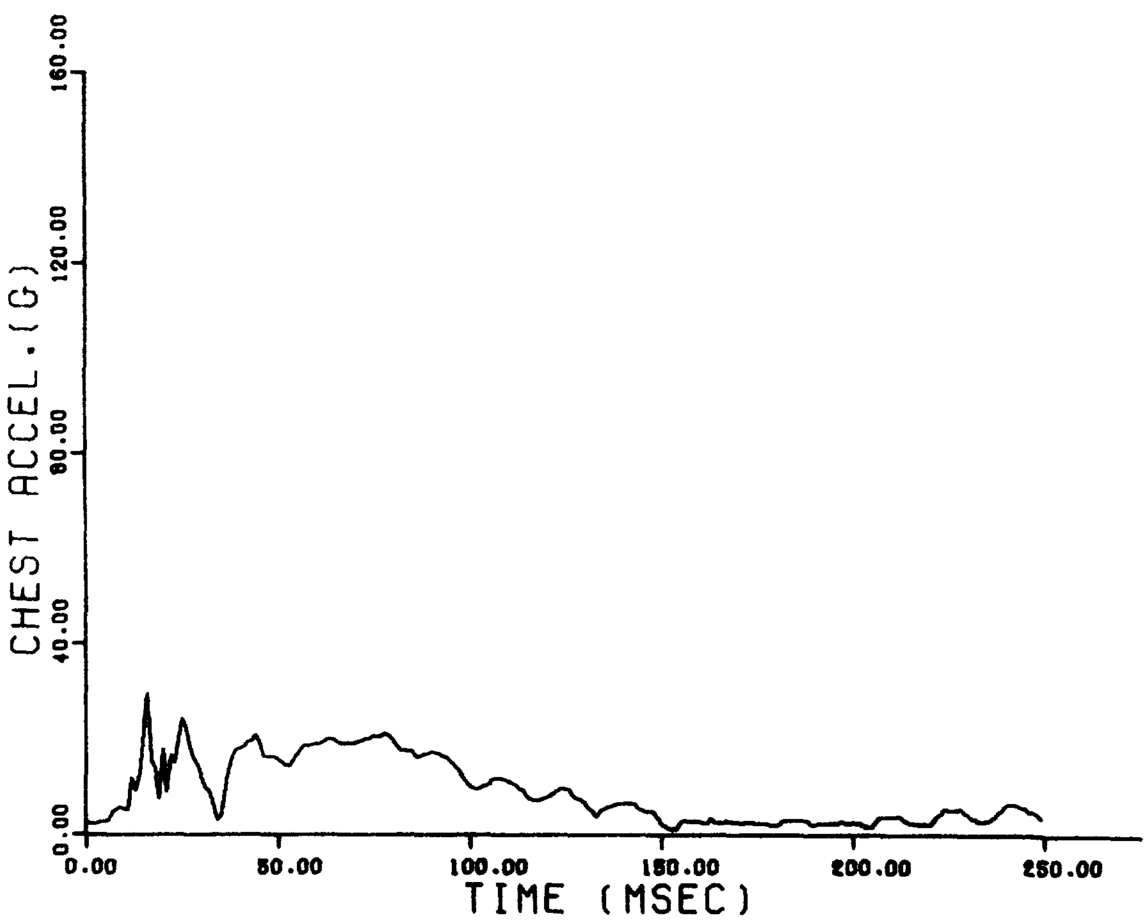
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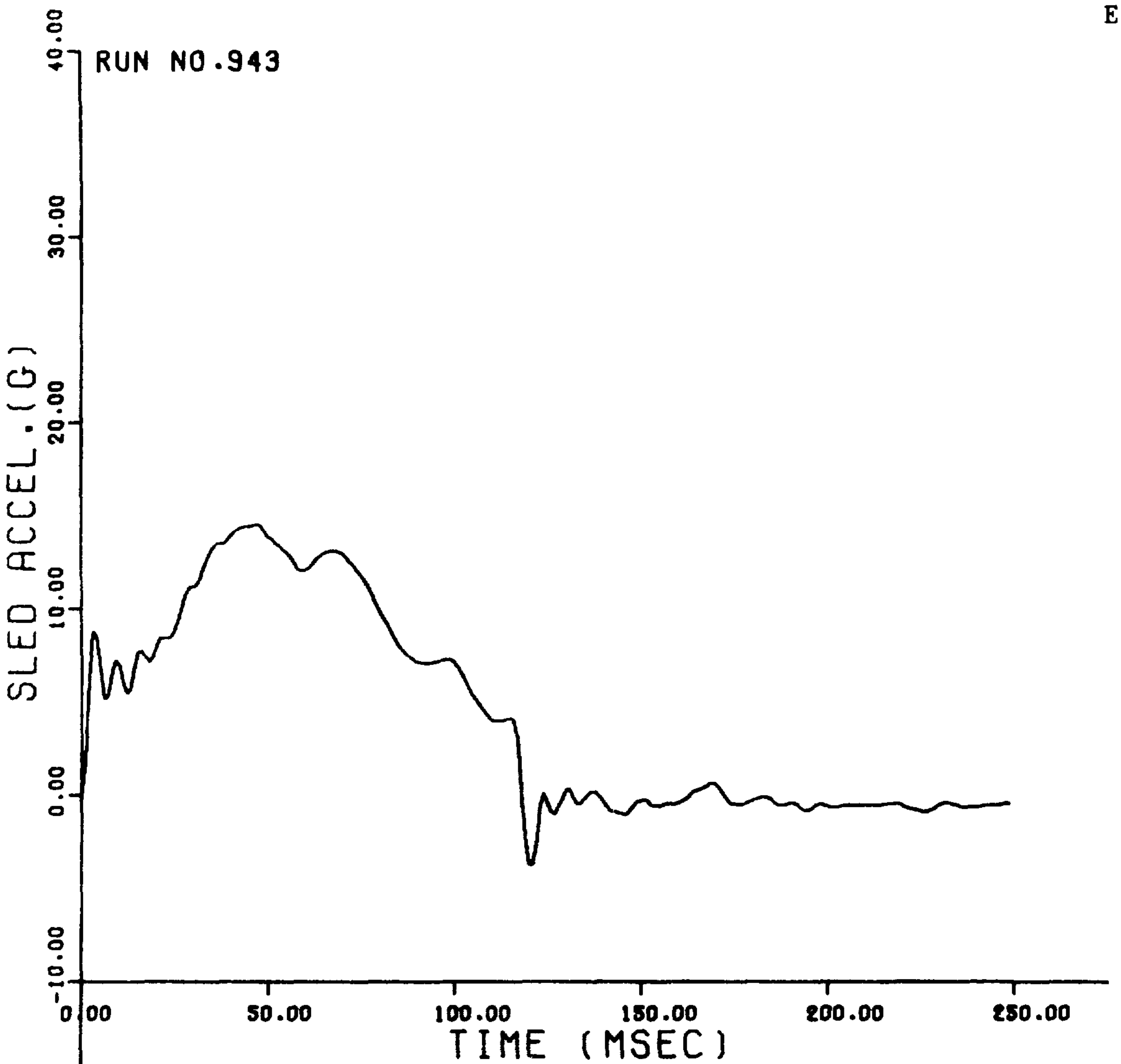
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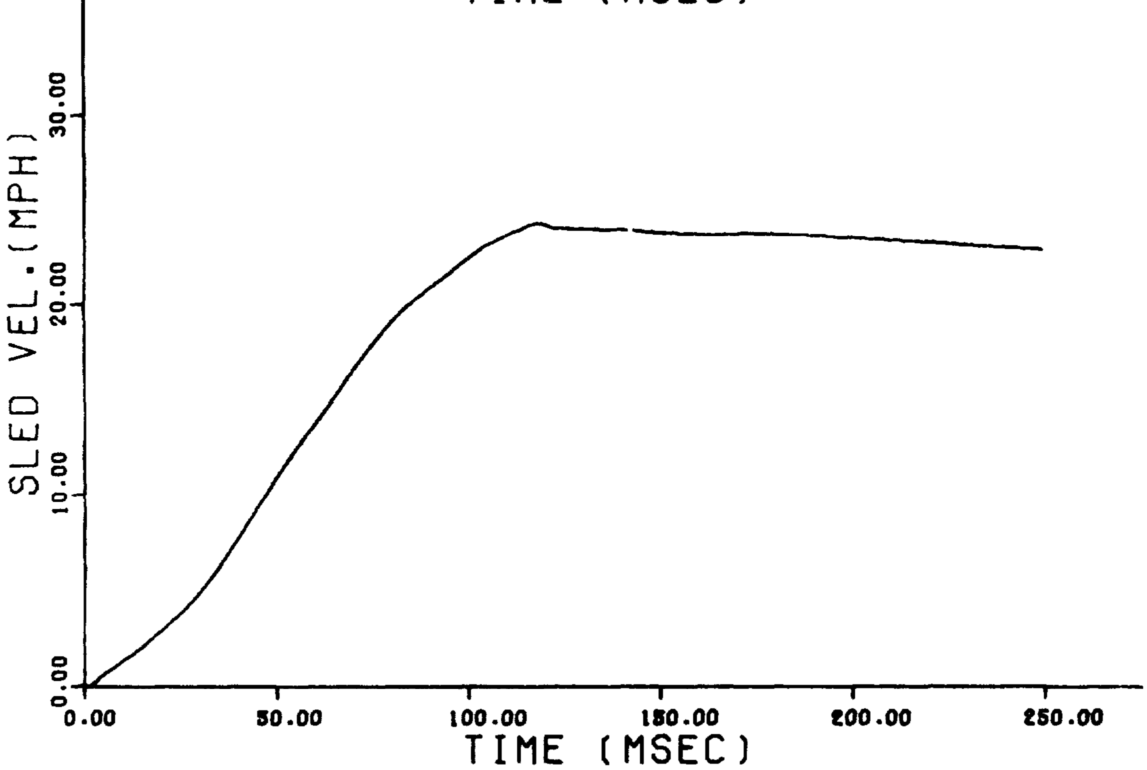
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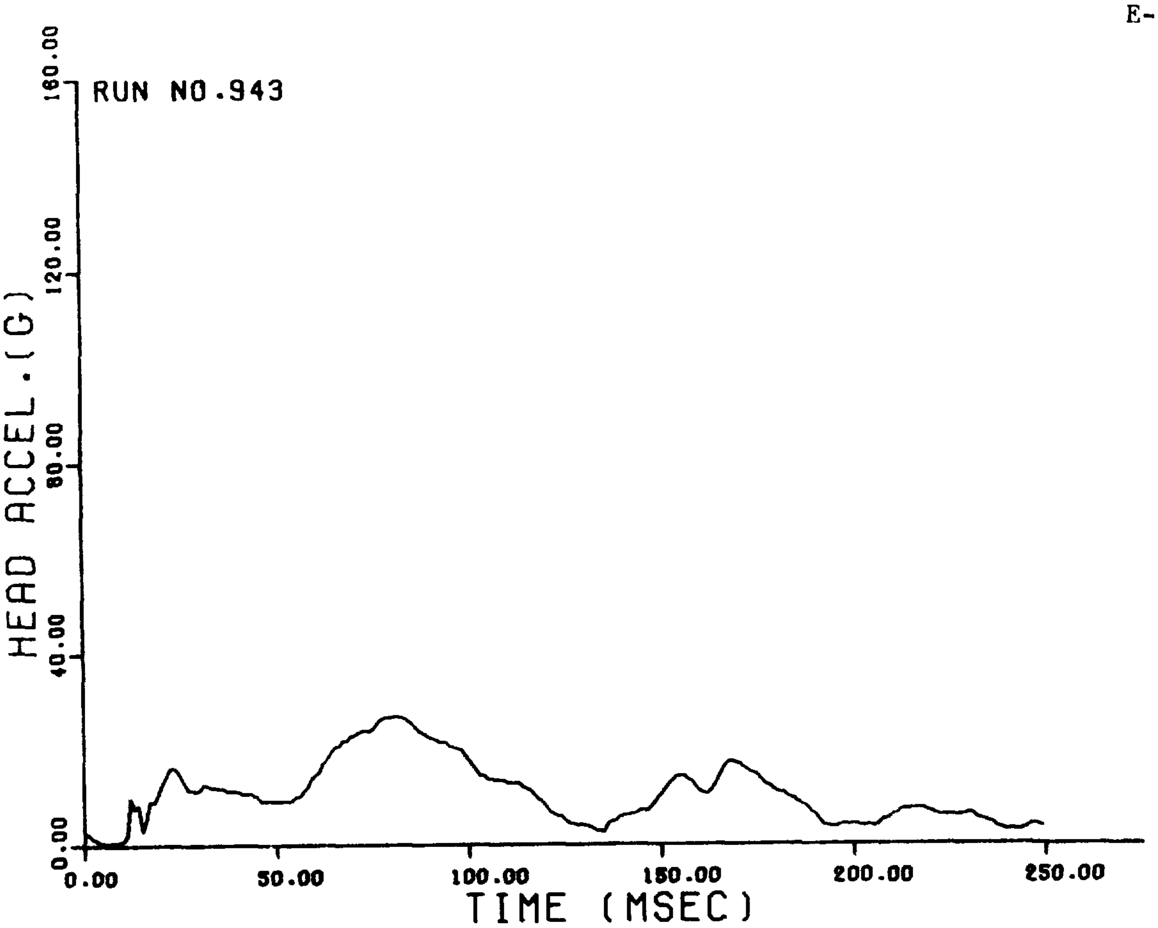
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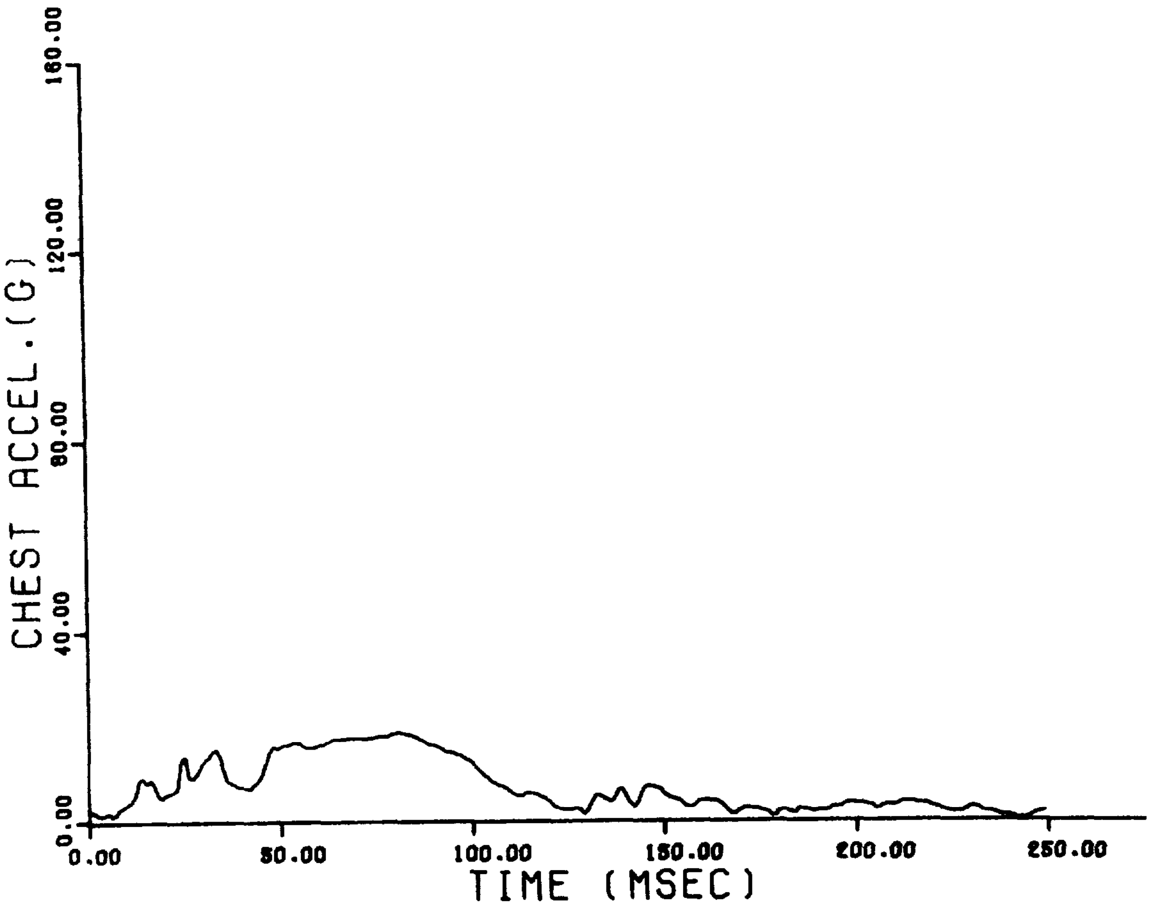
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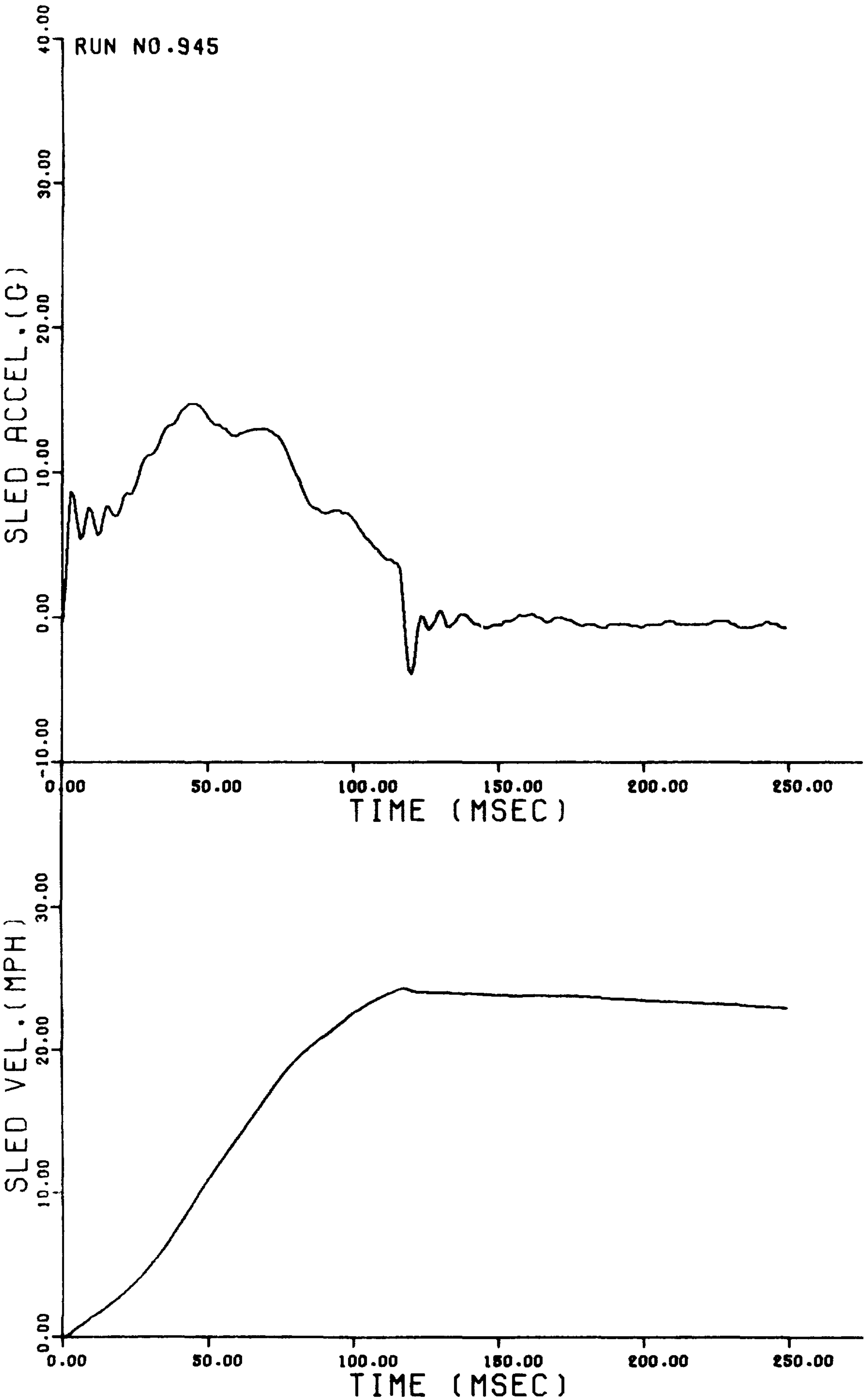
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250.00
TIME (MSEC)
SLED VEL.(MPH)
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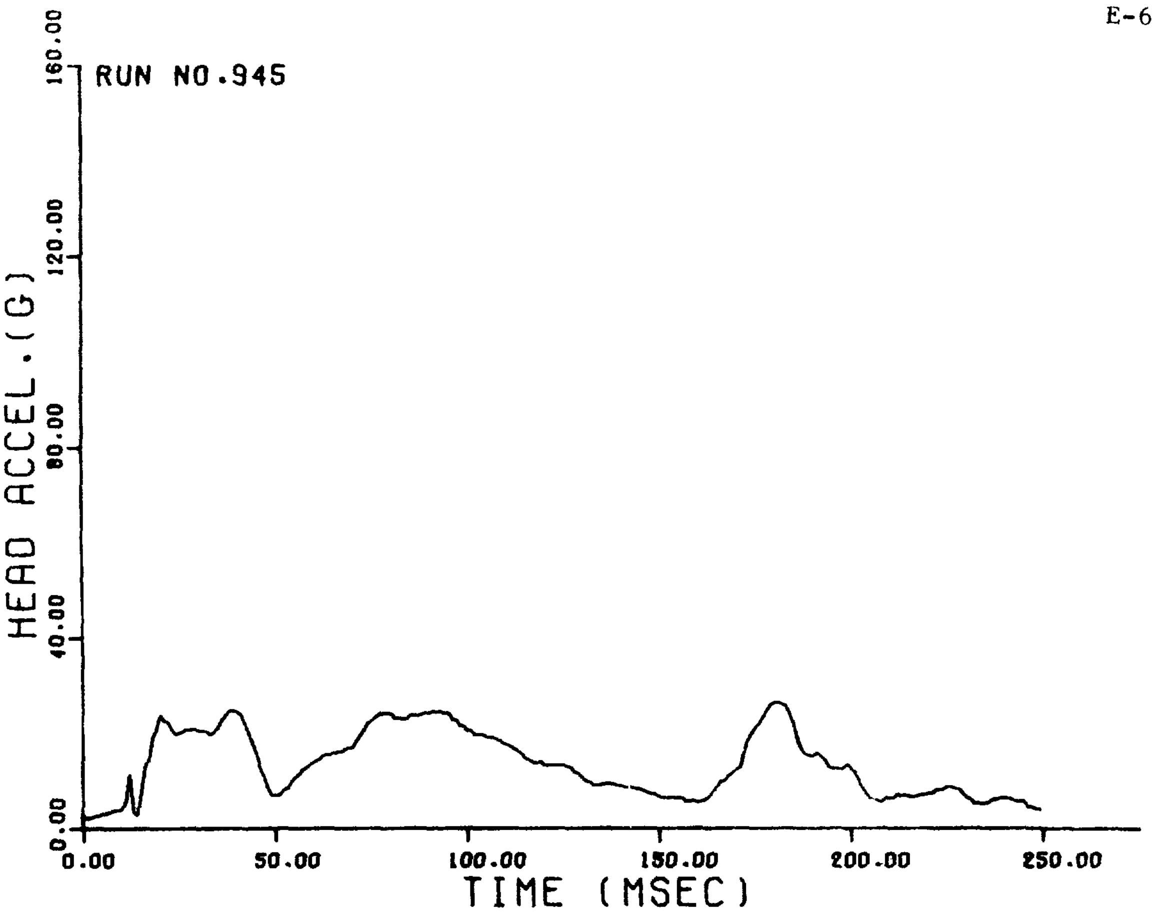
TIME (MSEC)



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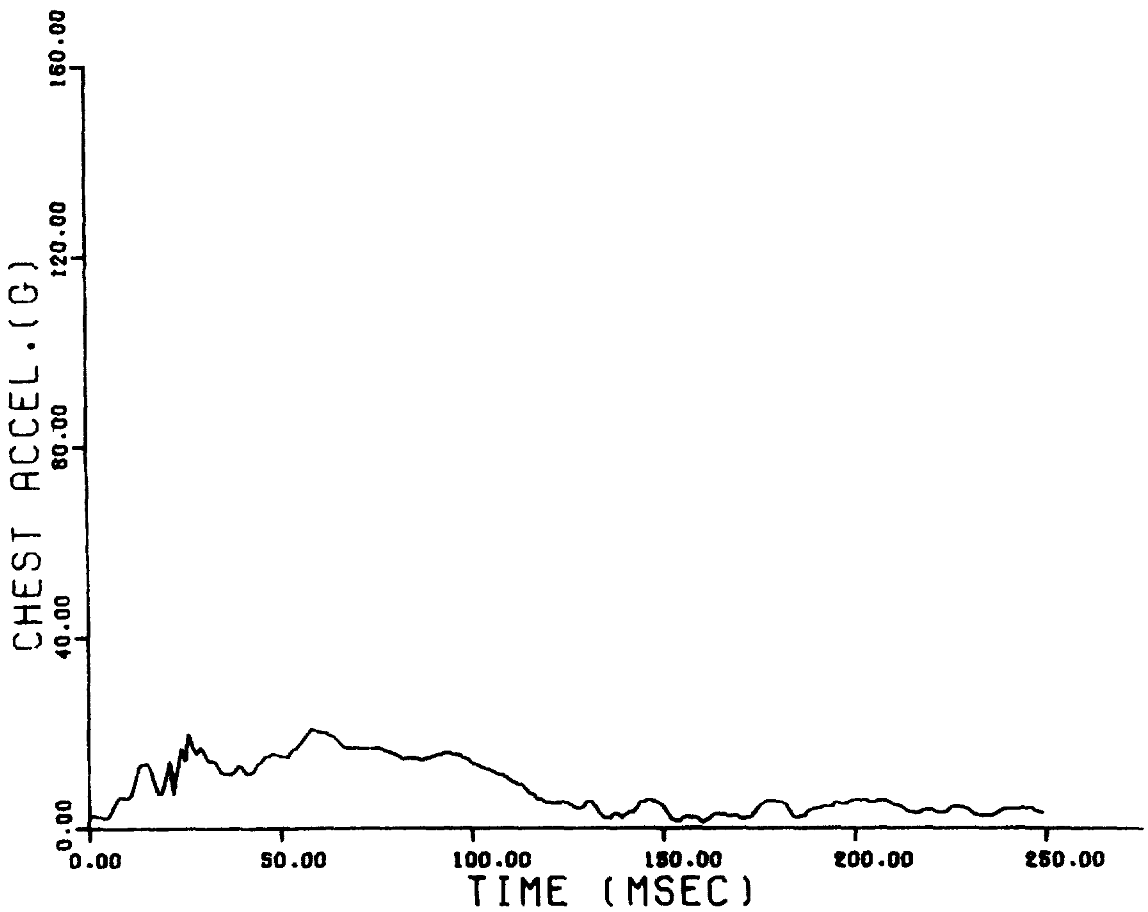

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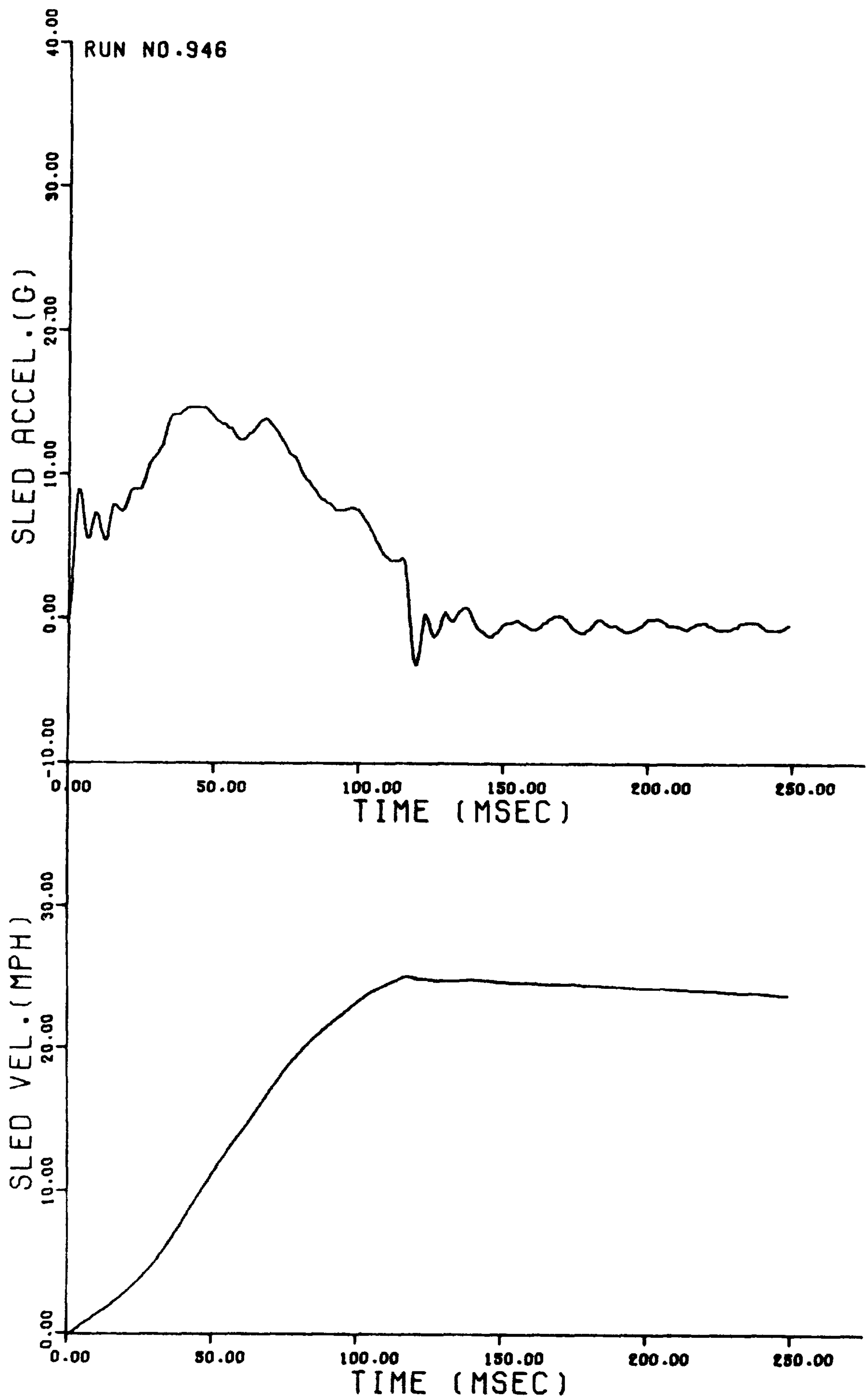
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TIME (MSEC)
SLED VEL.(MPH)
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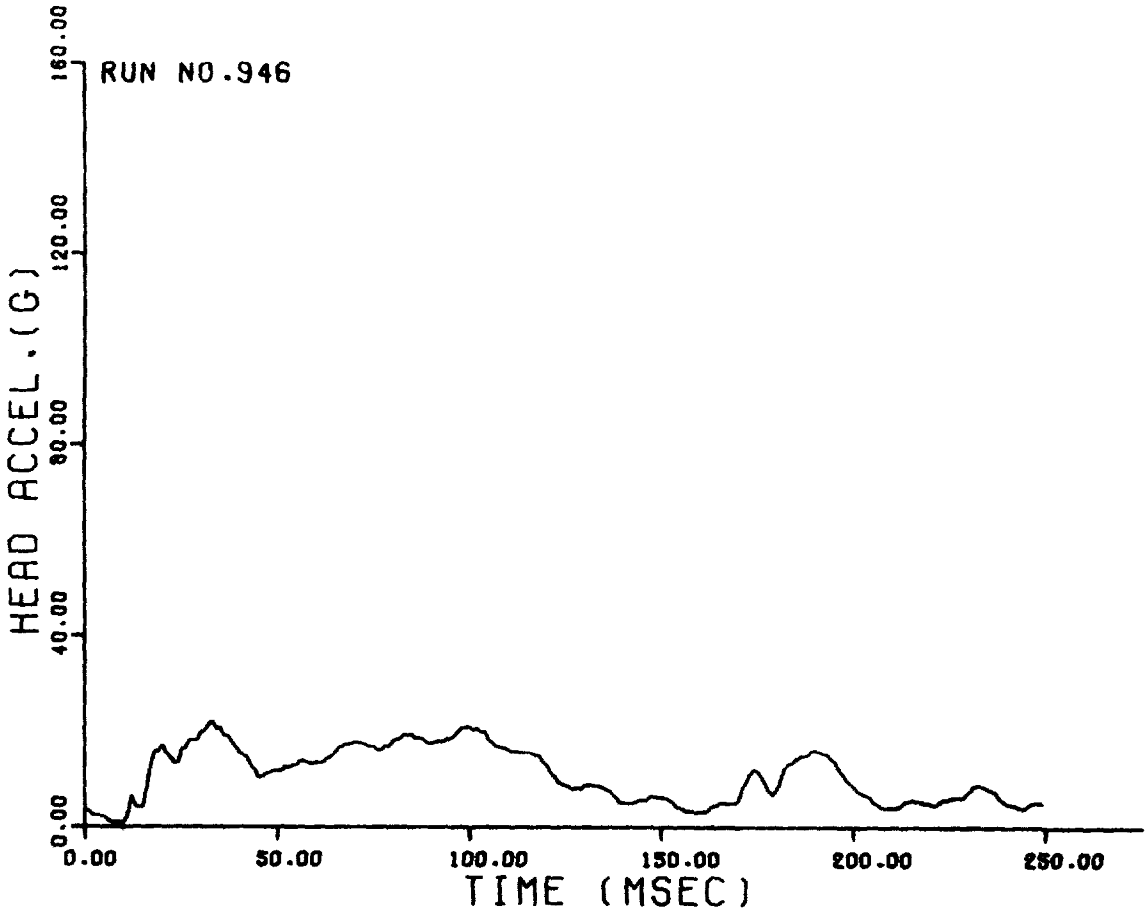
TIME (MSEC)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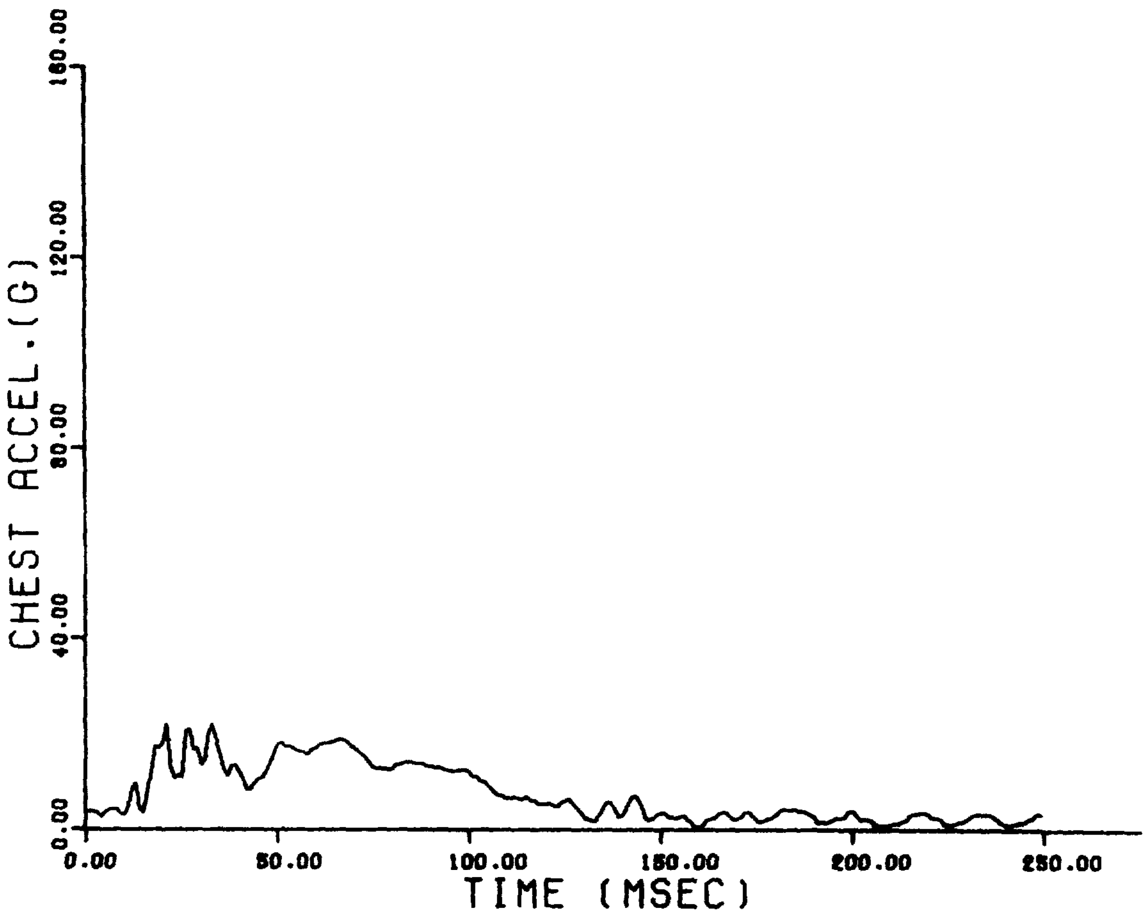
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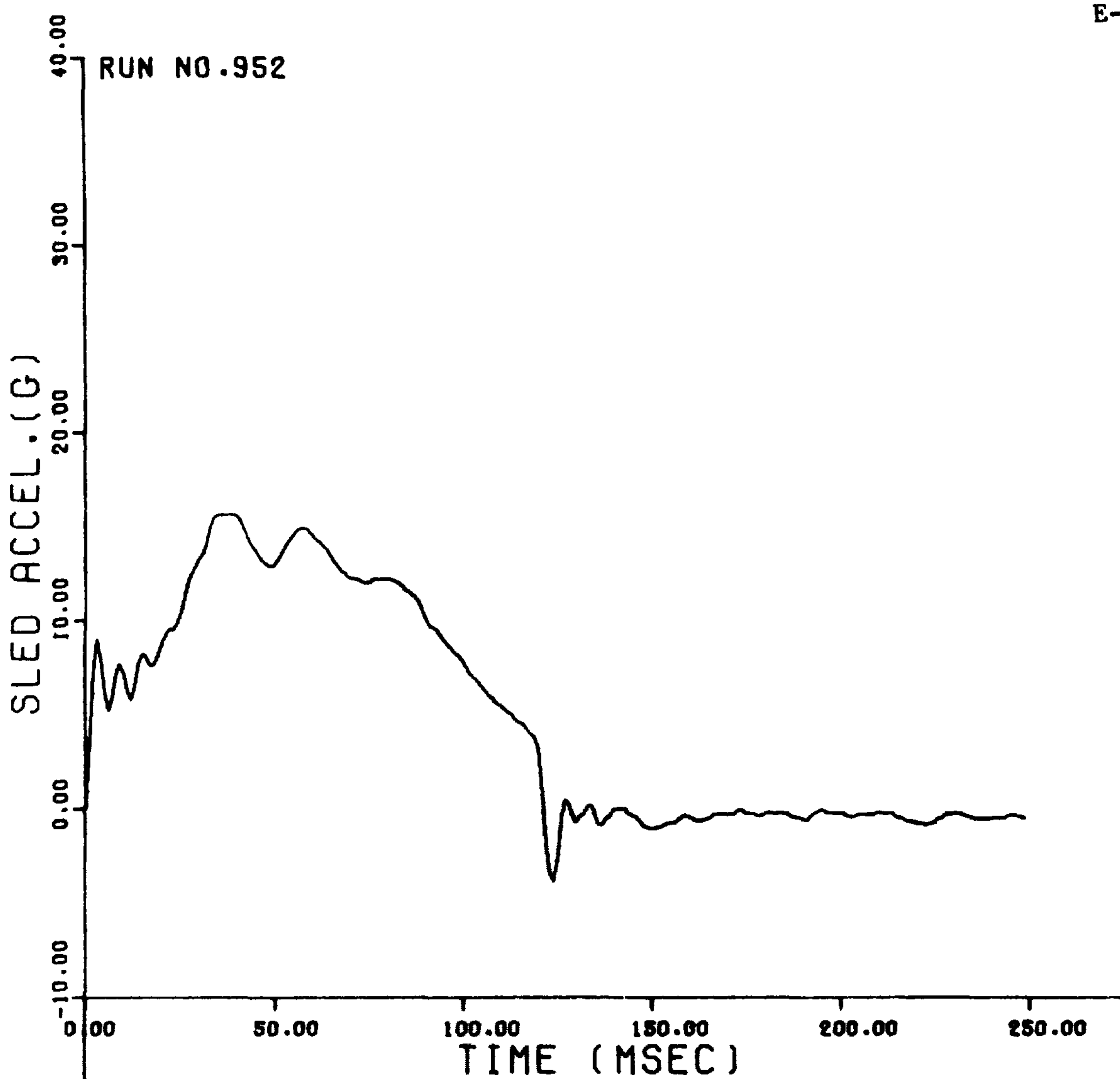
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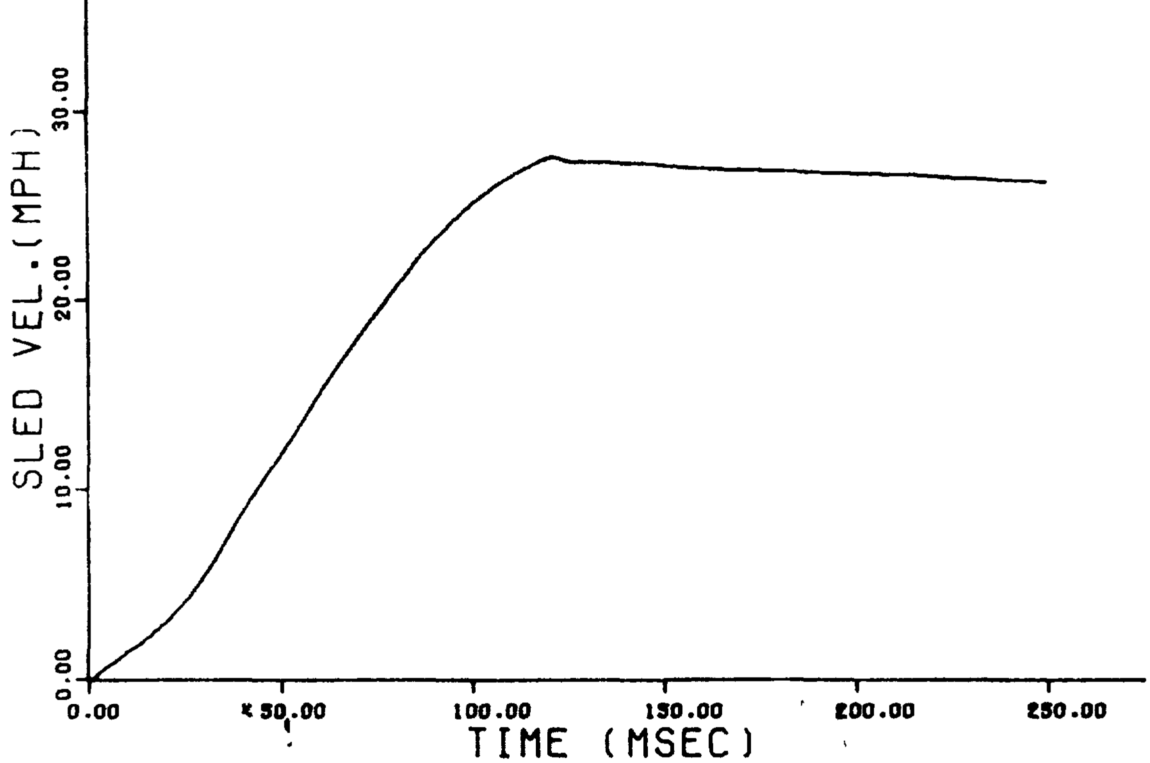
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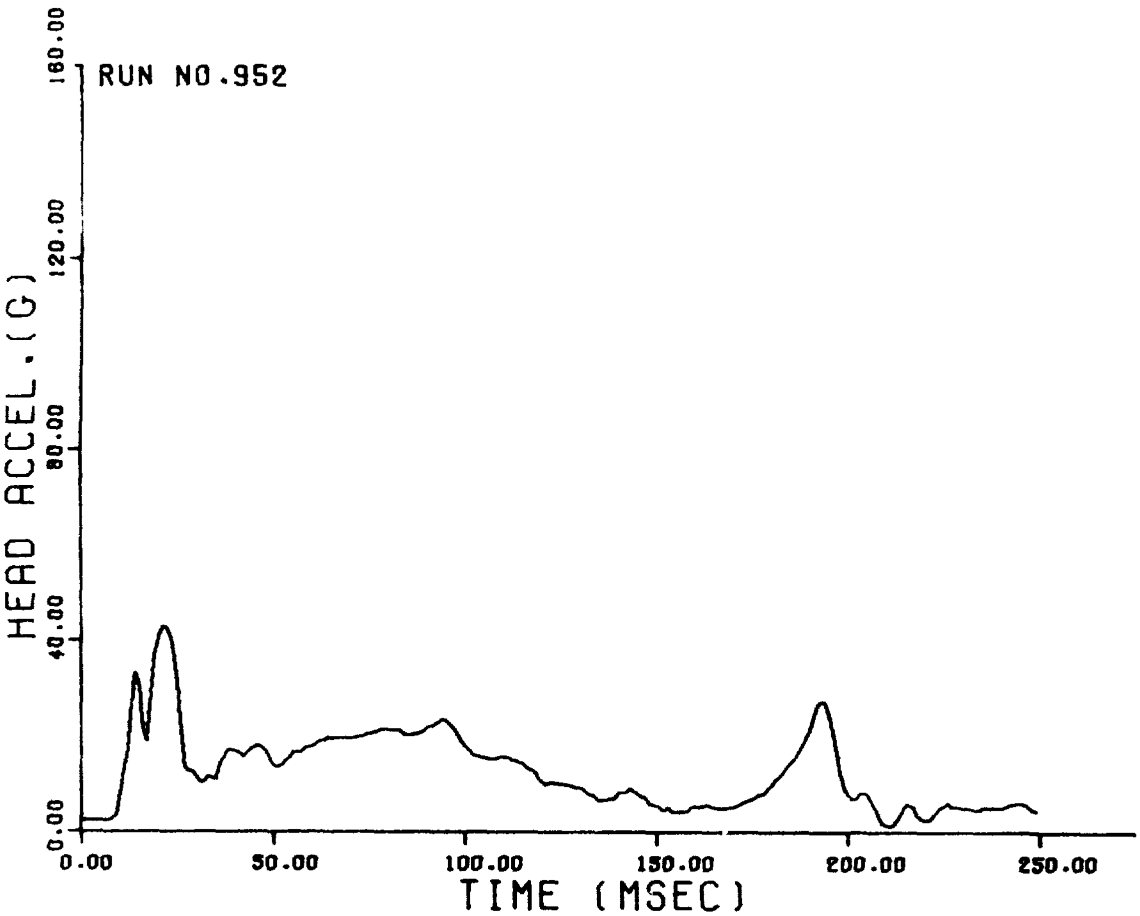
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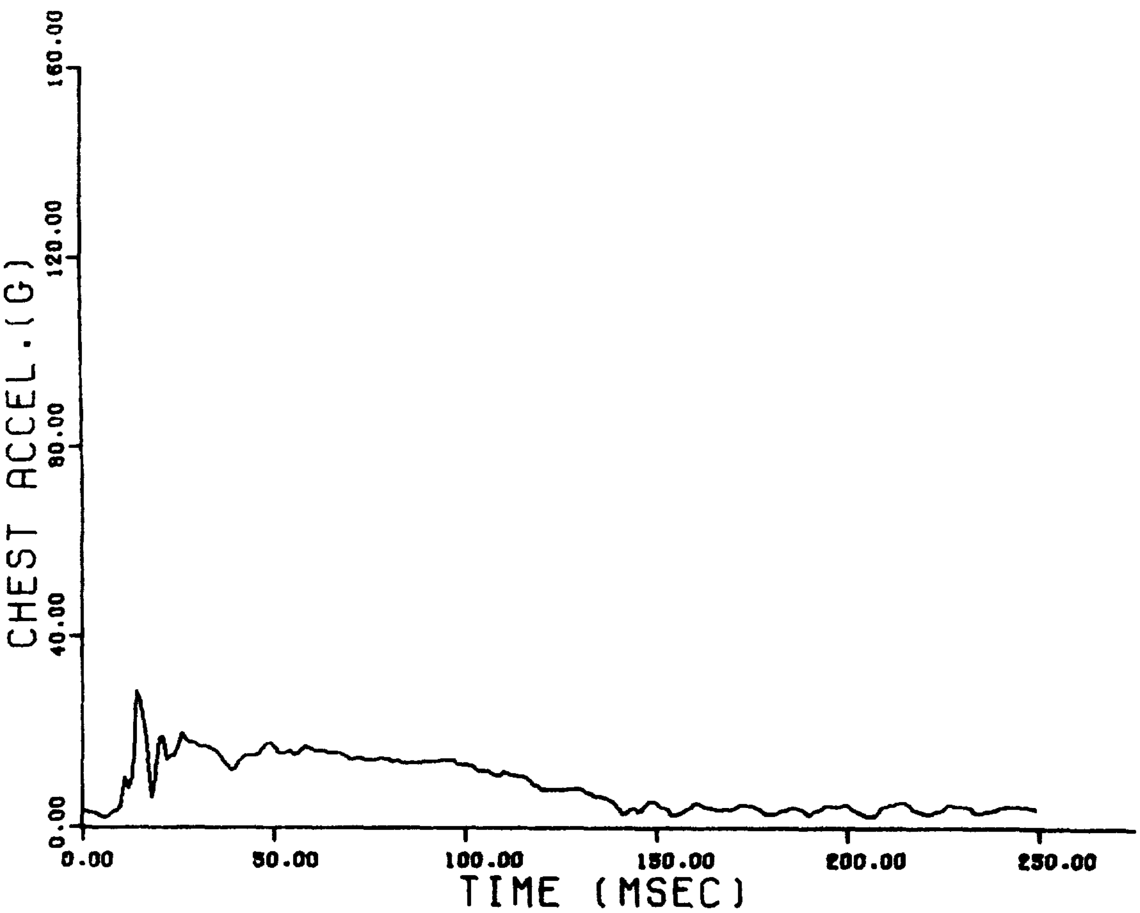
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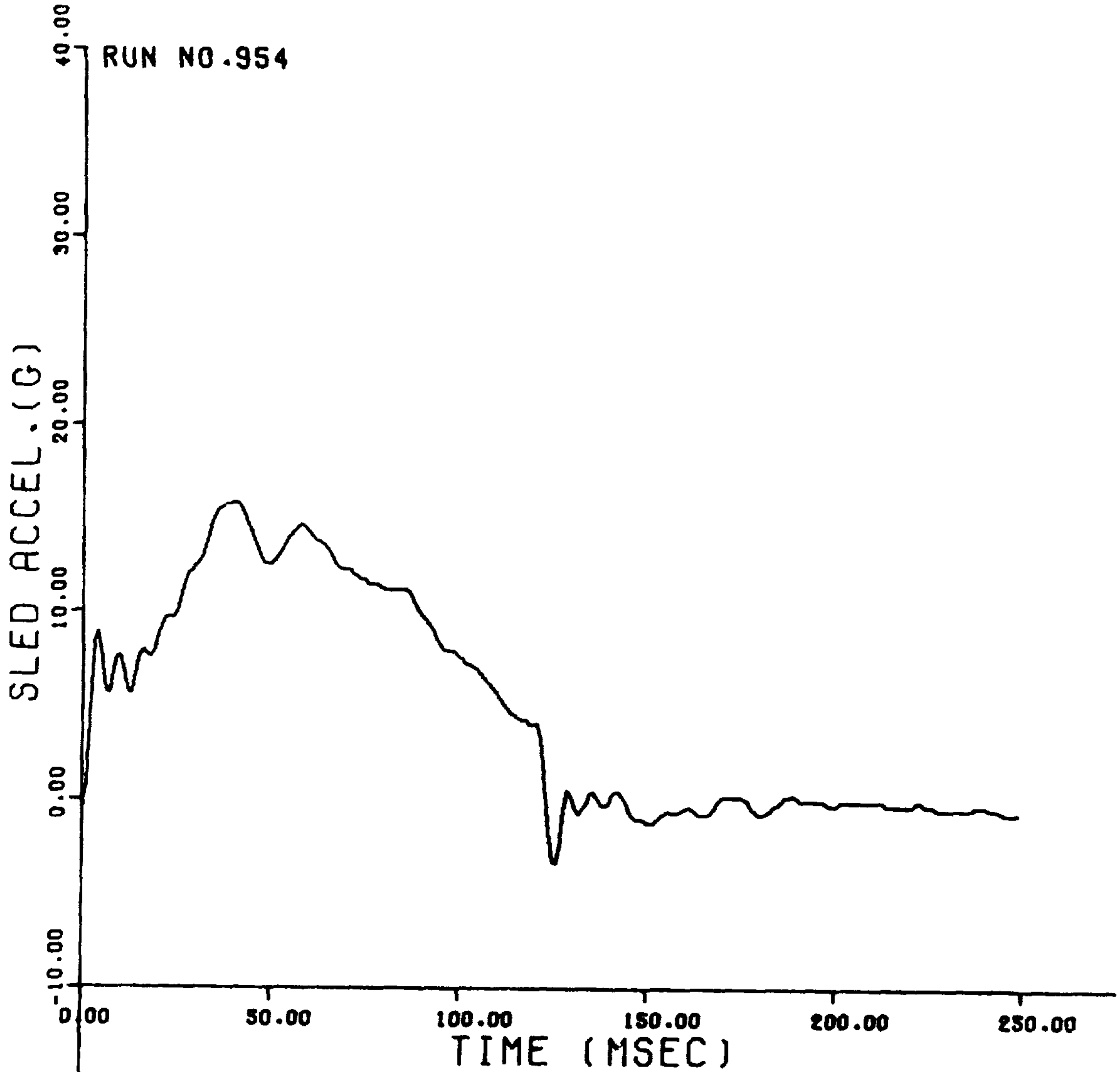
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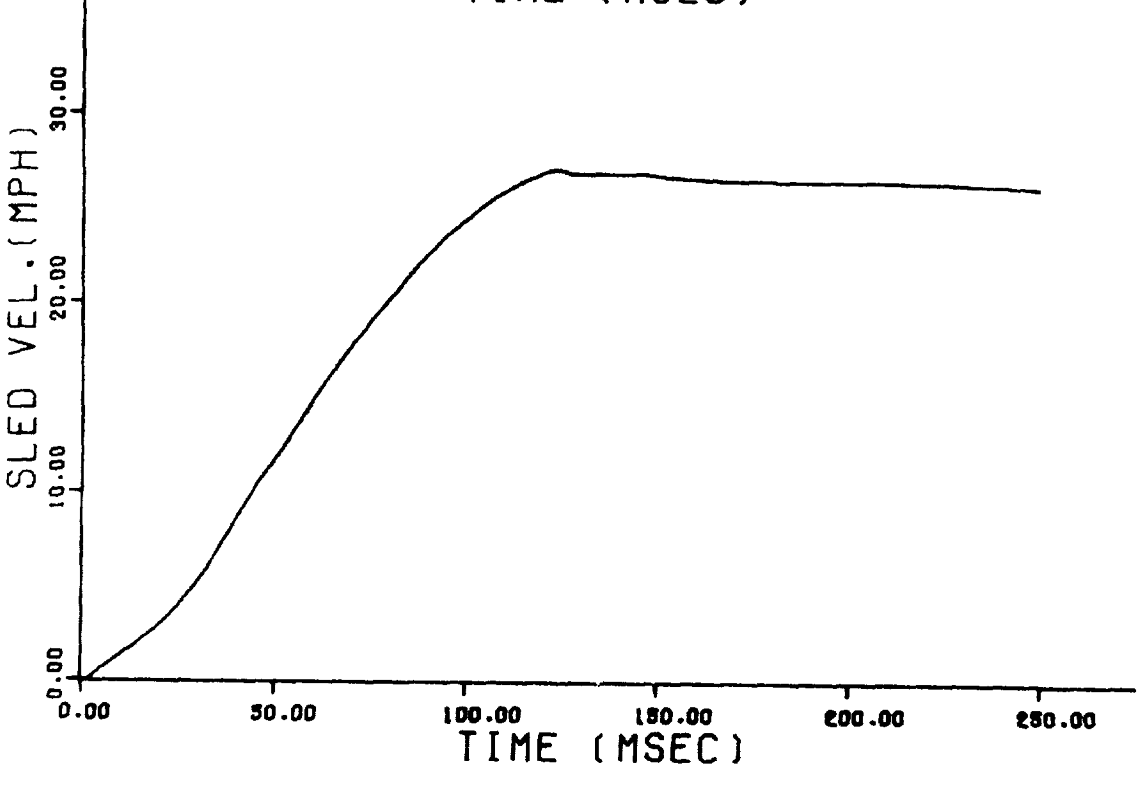
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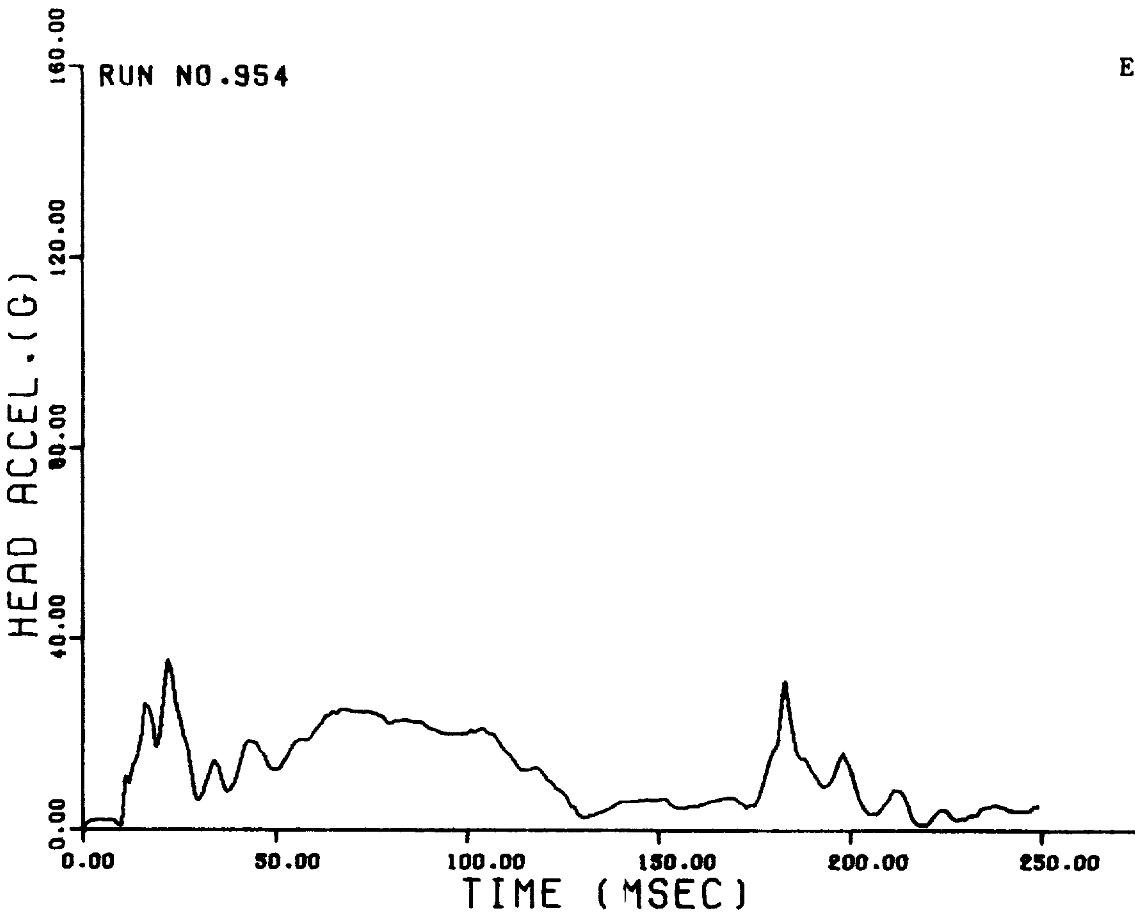
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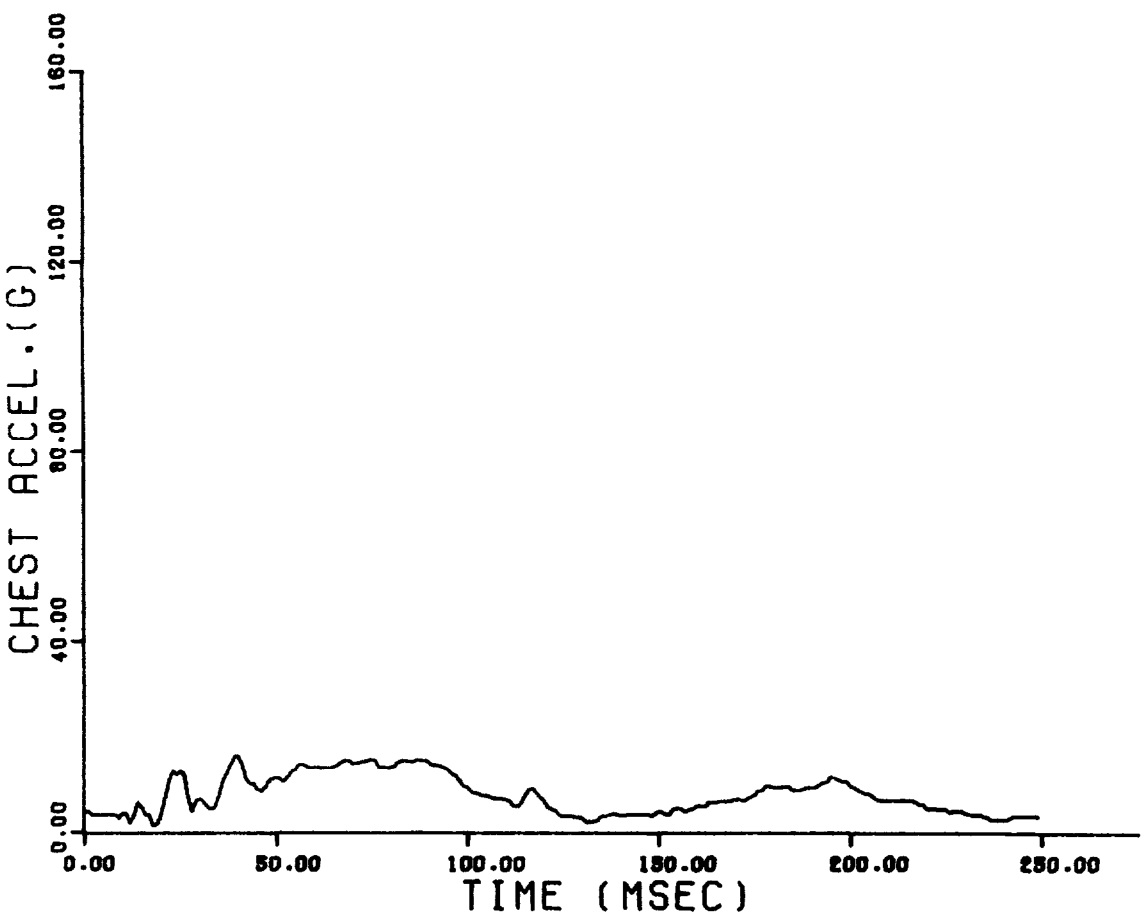
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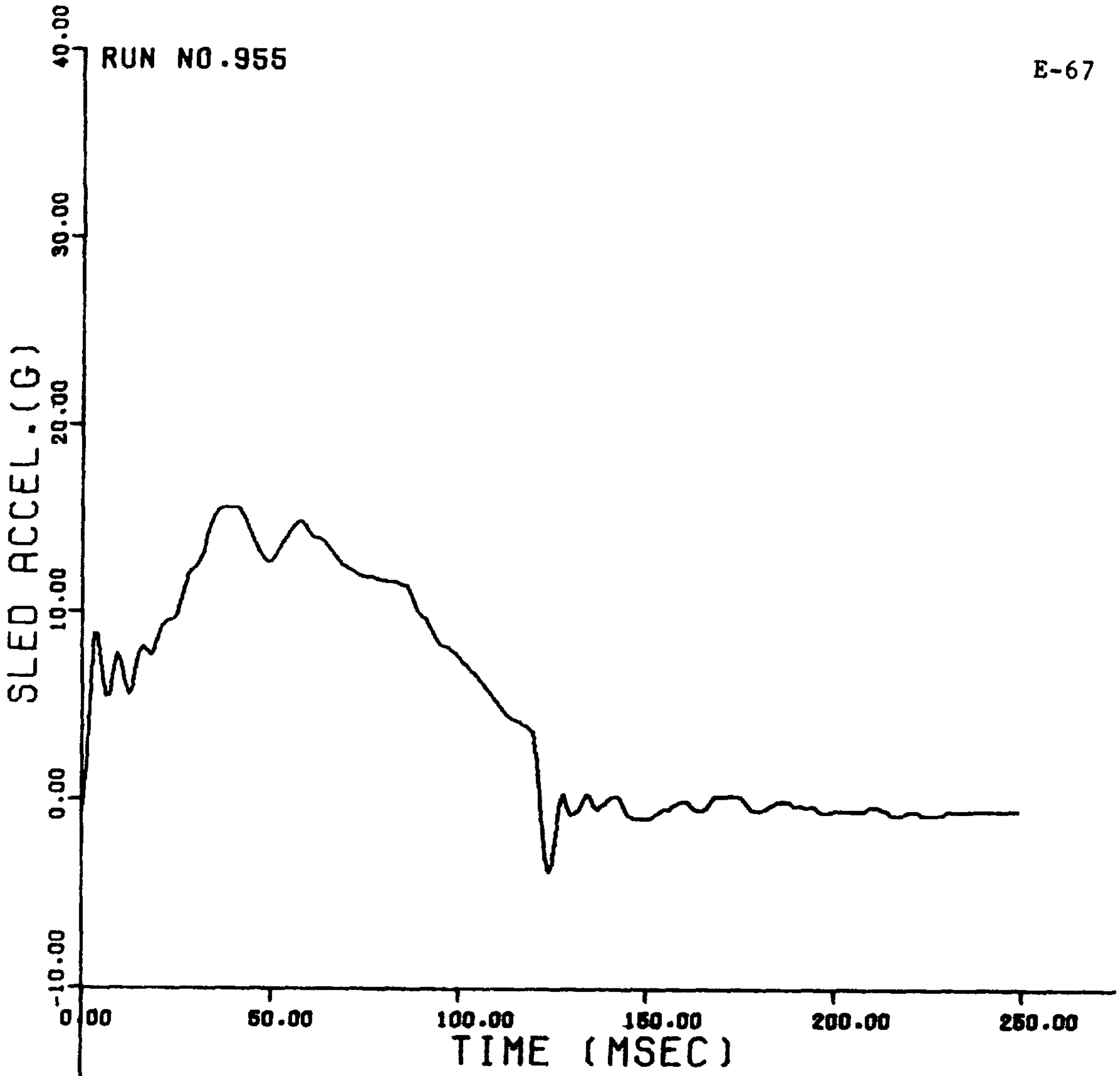

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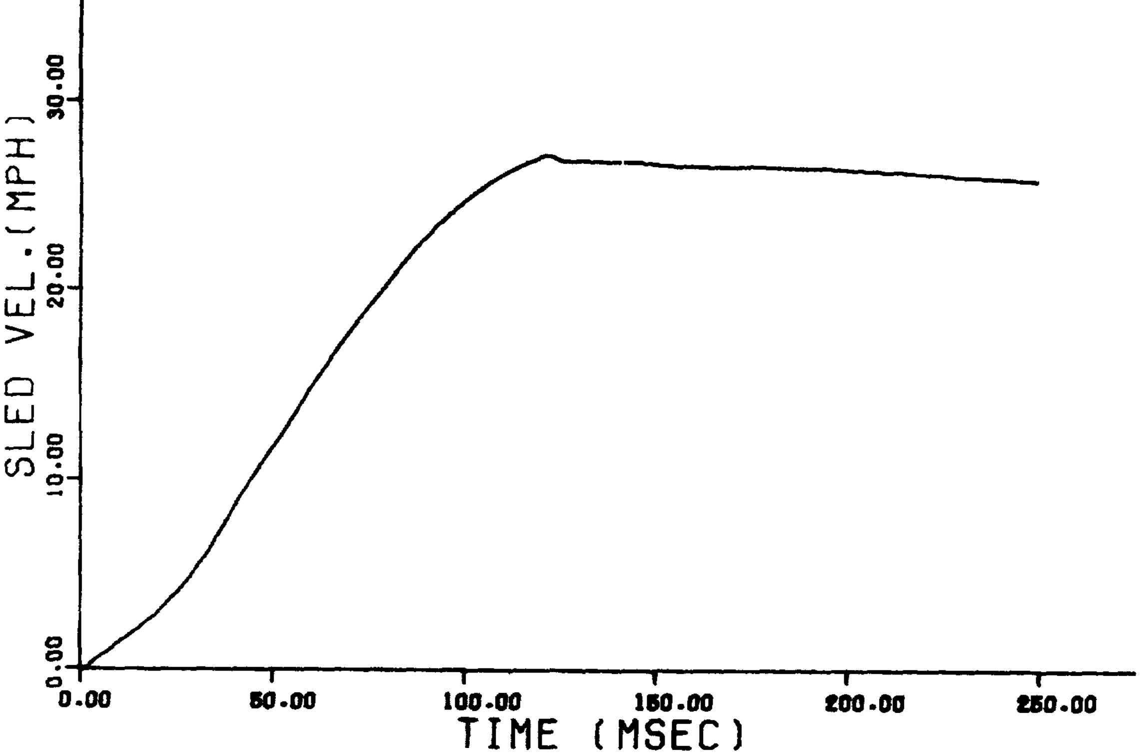

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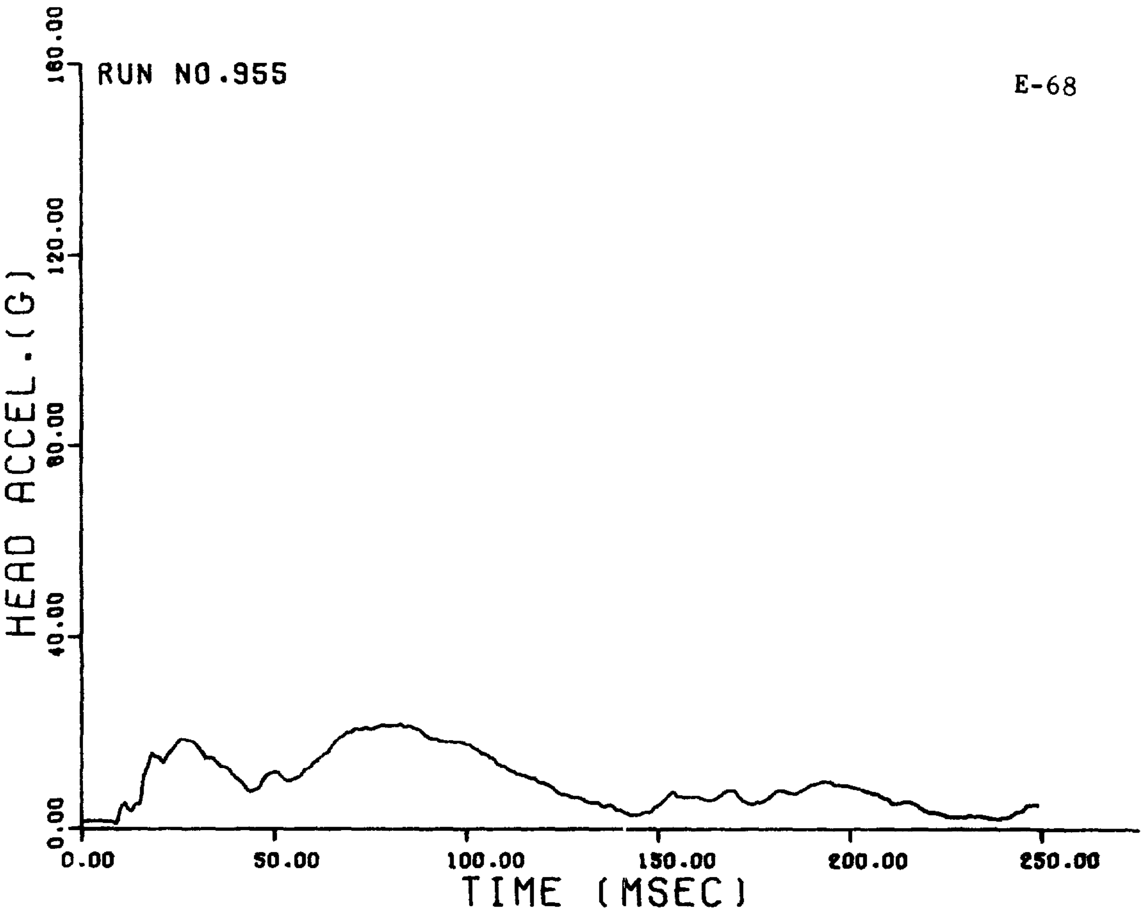
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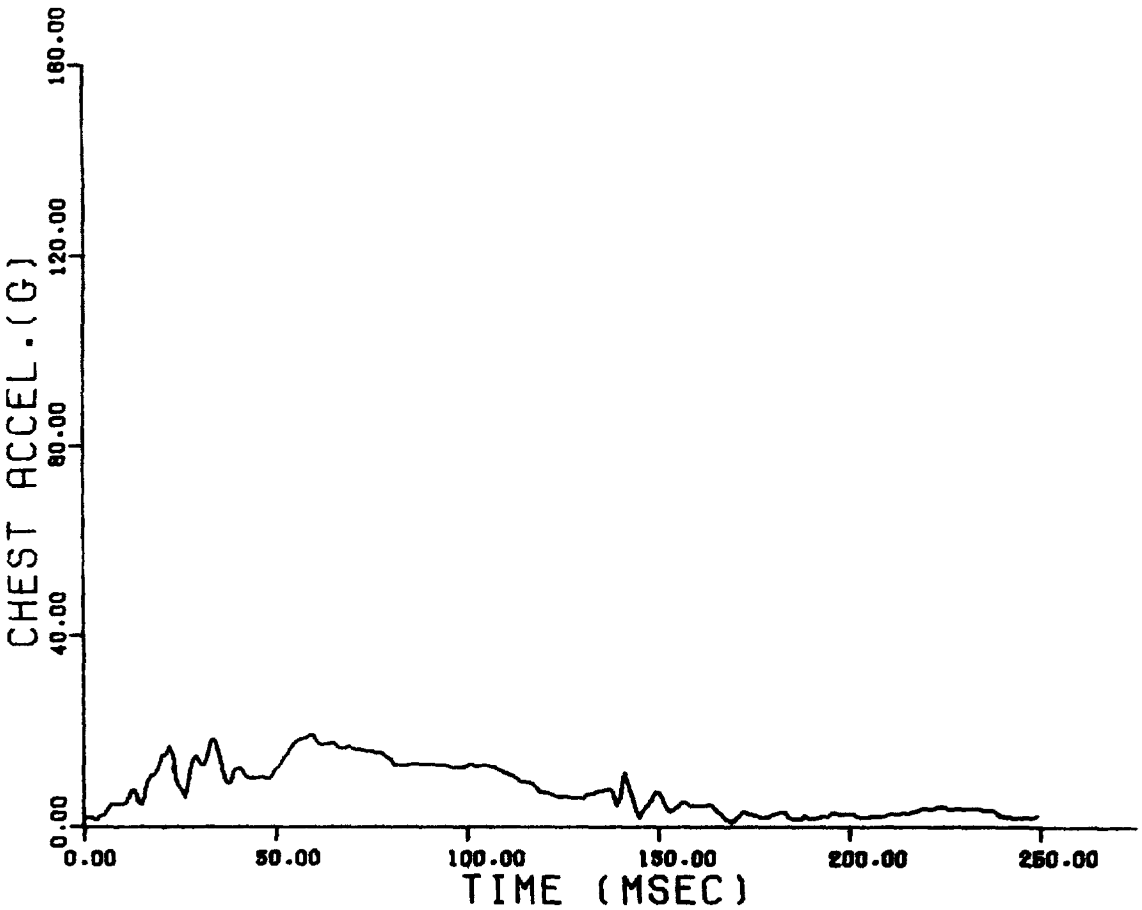
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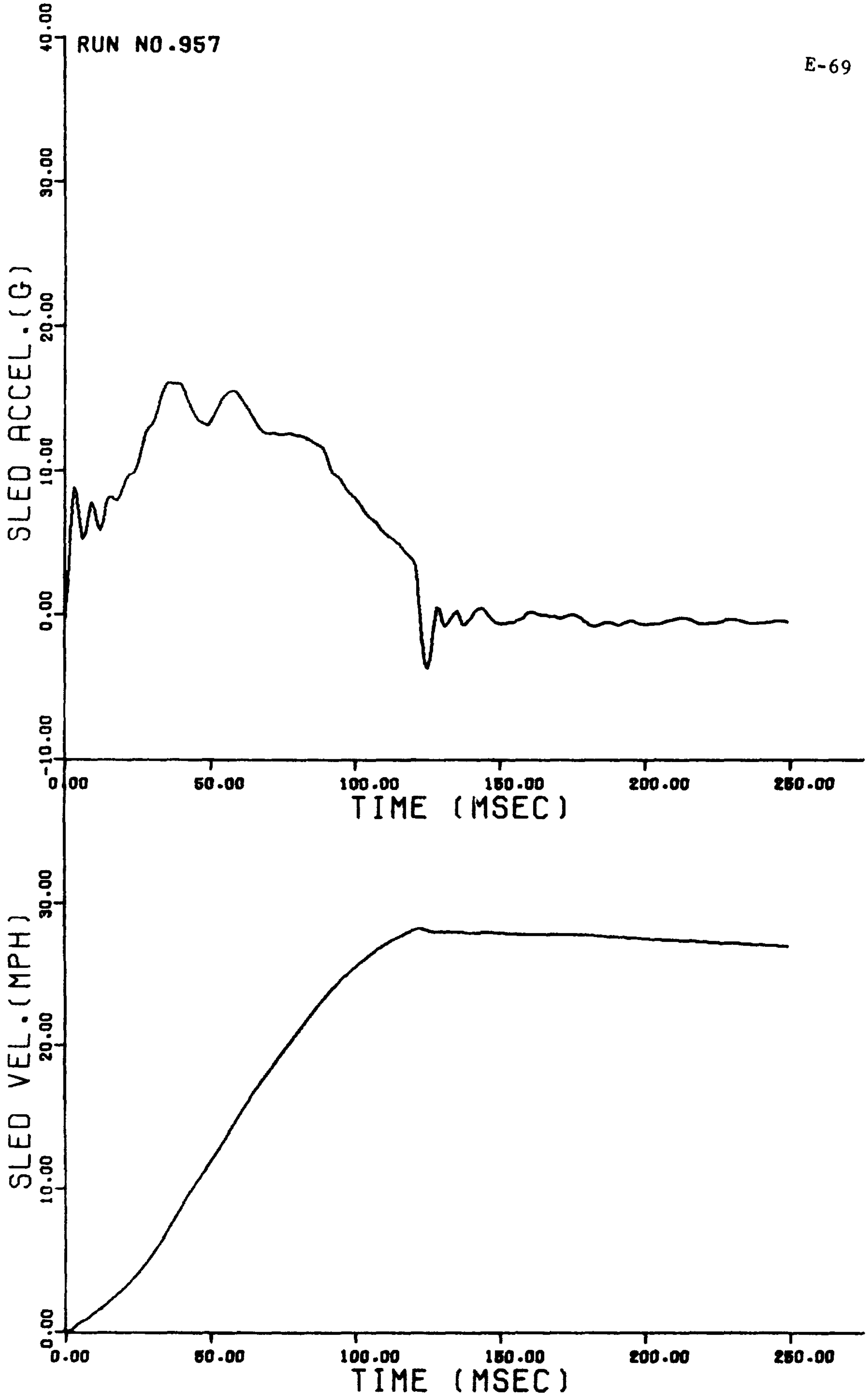
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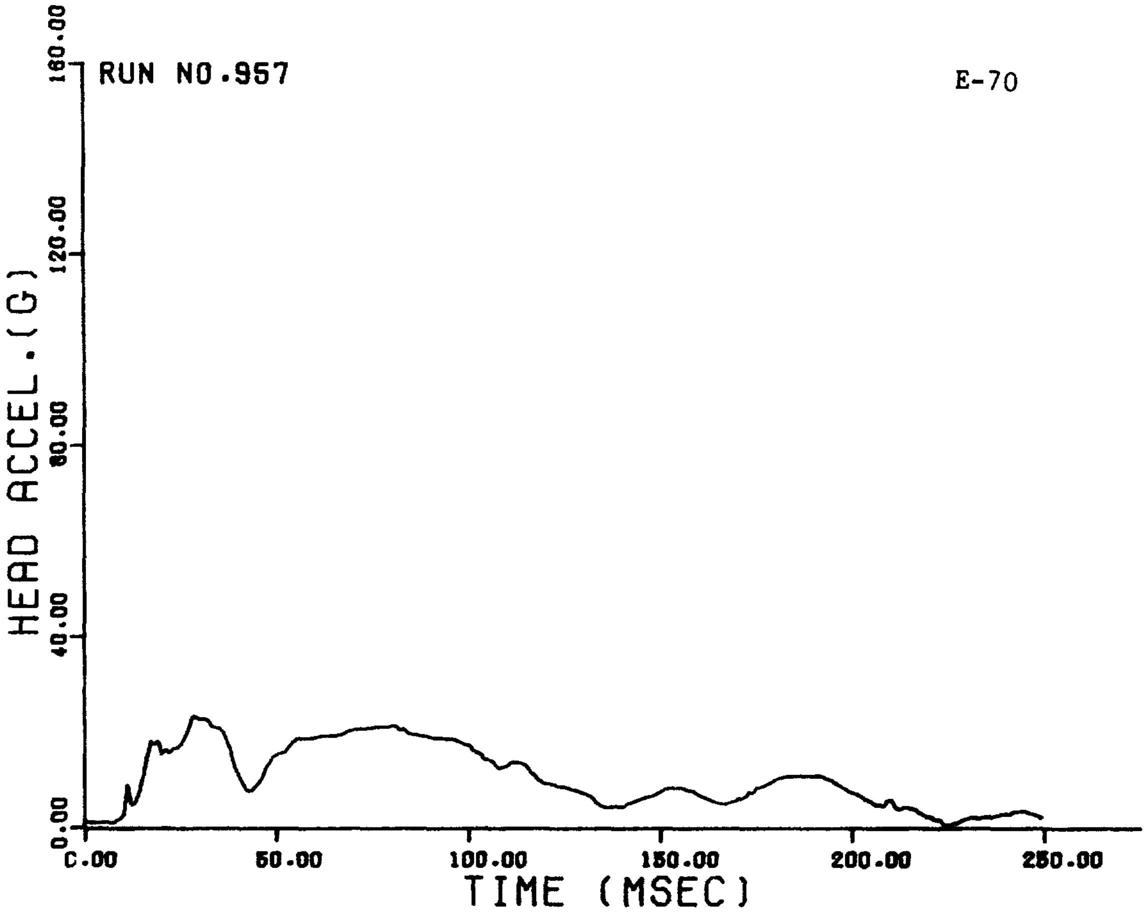
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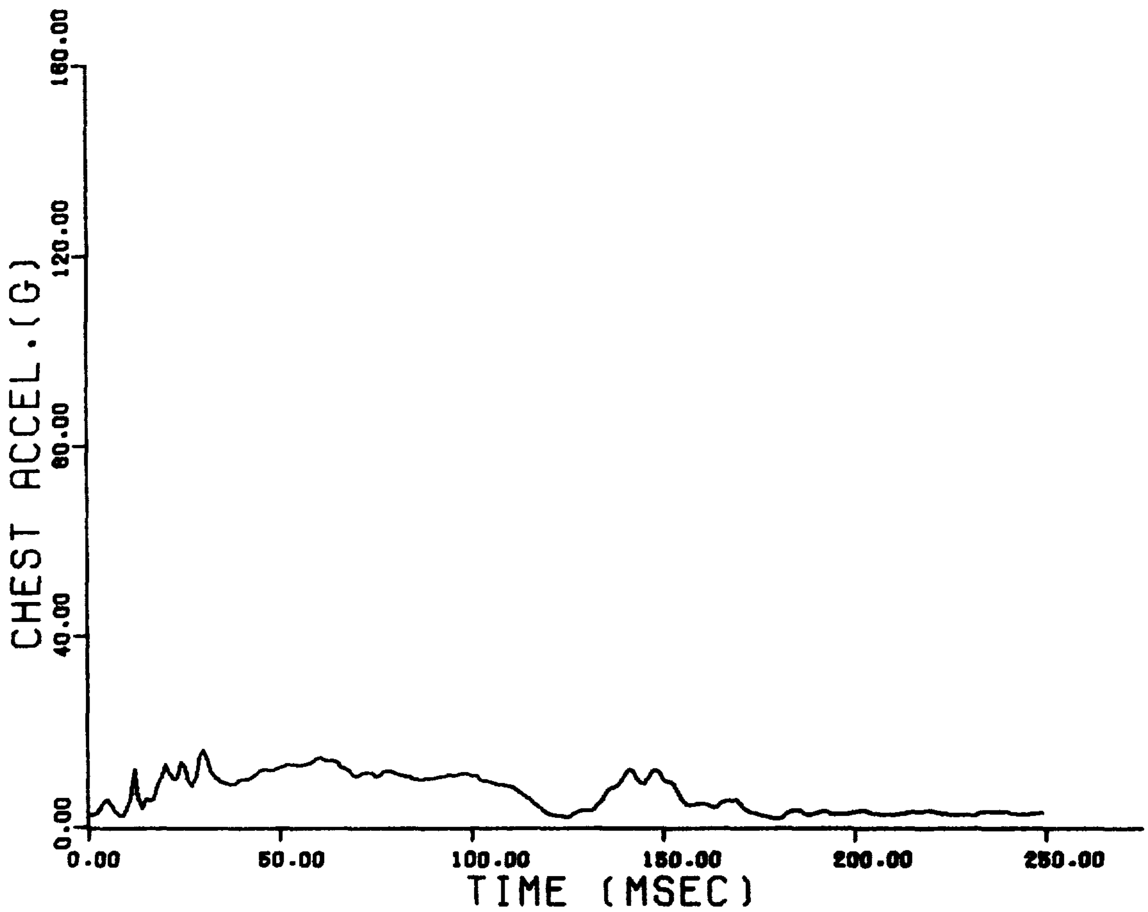
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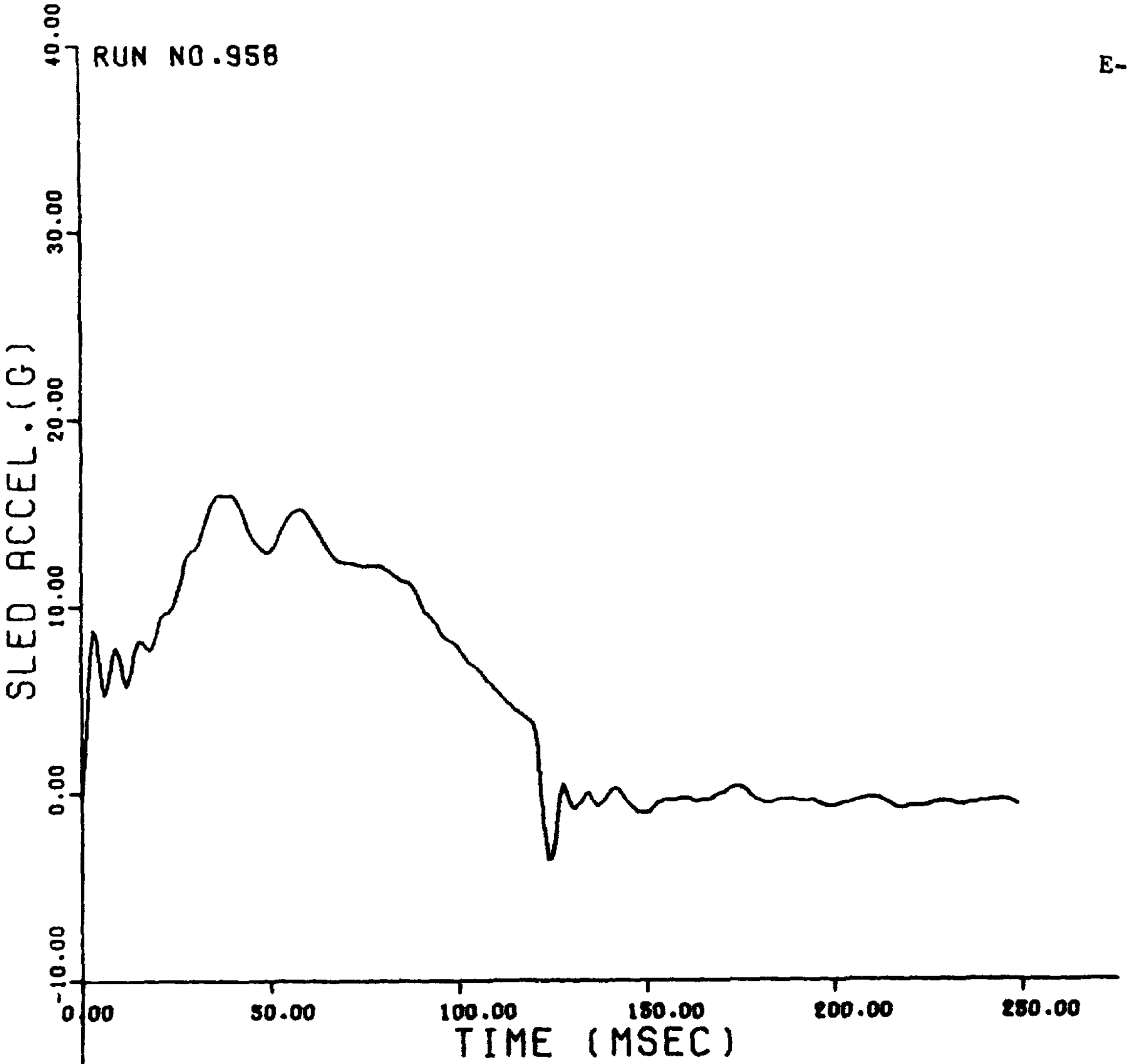
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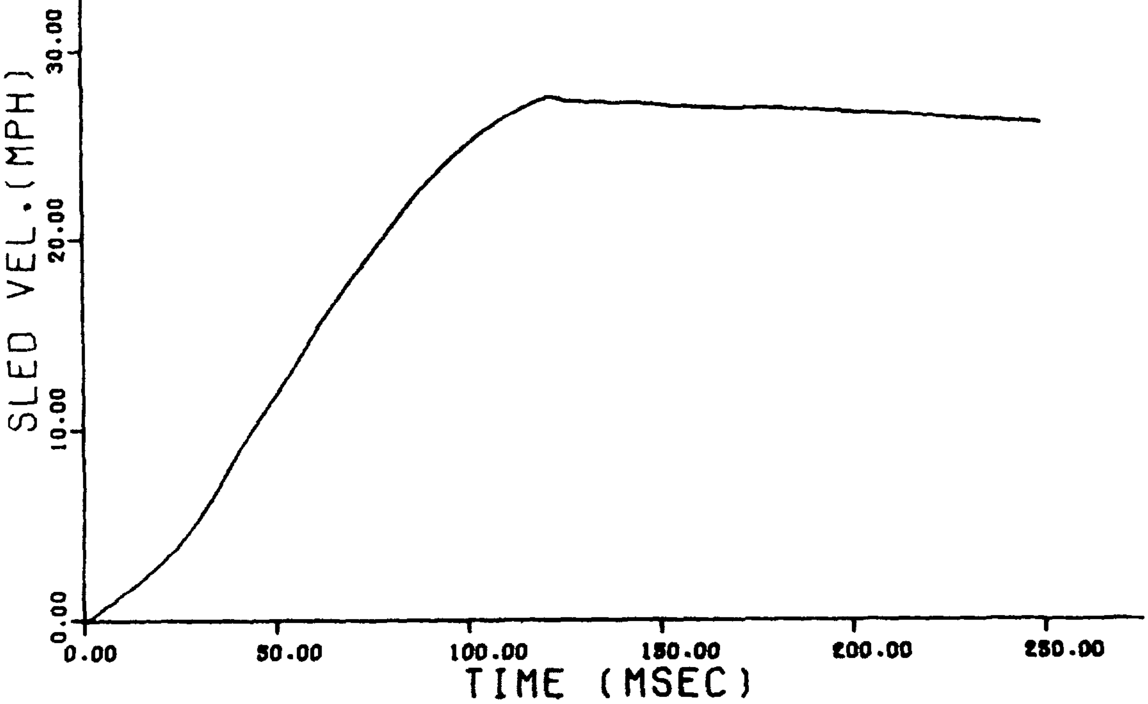
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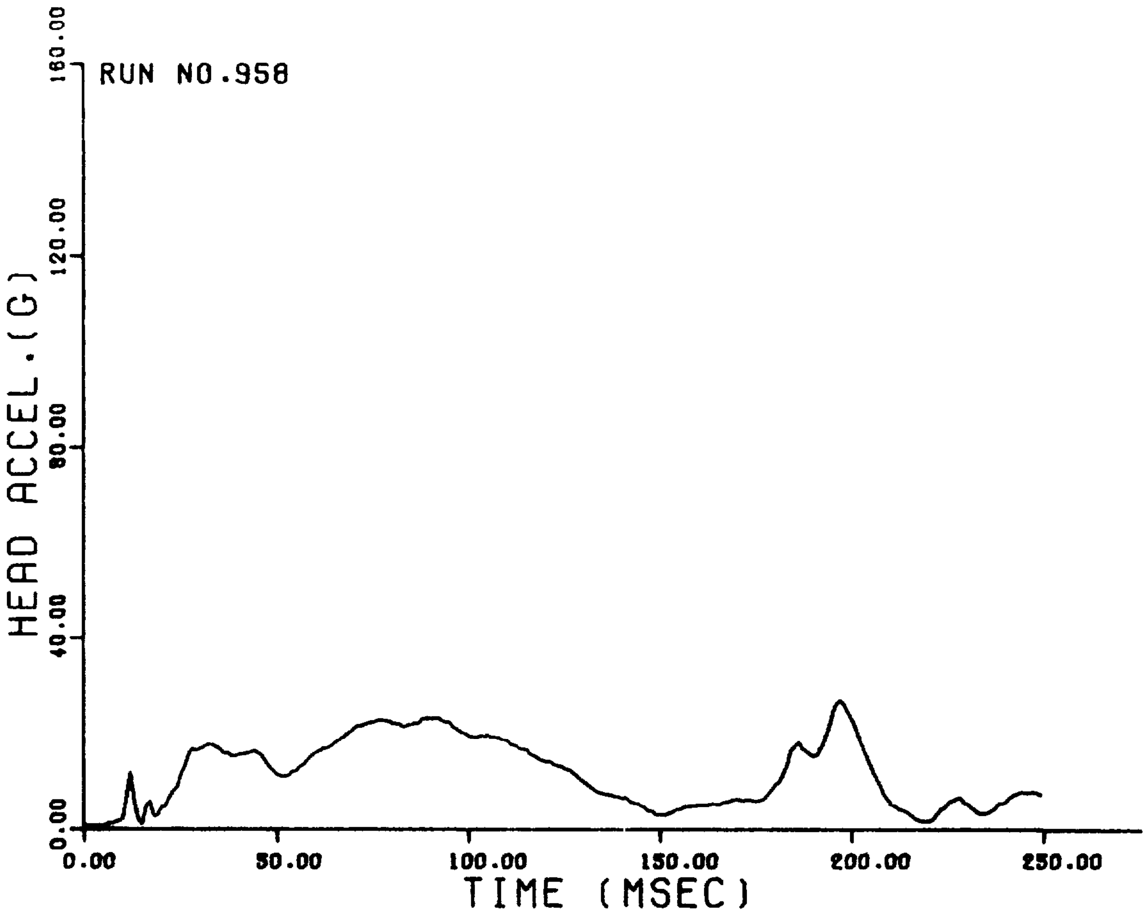
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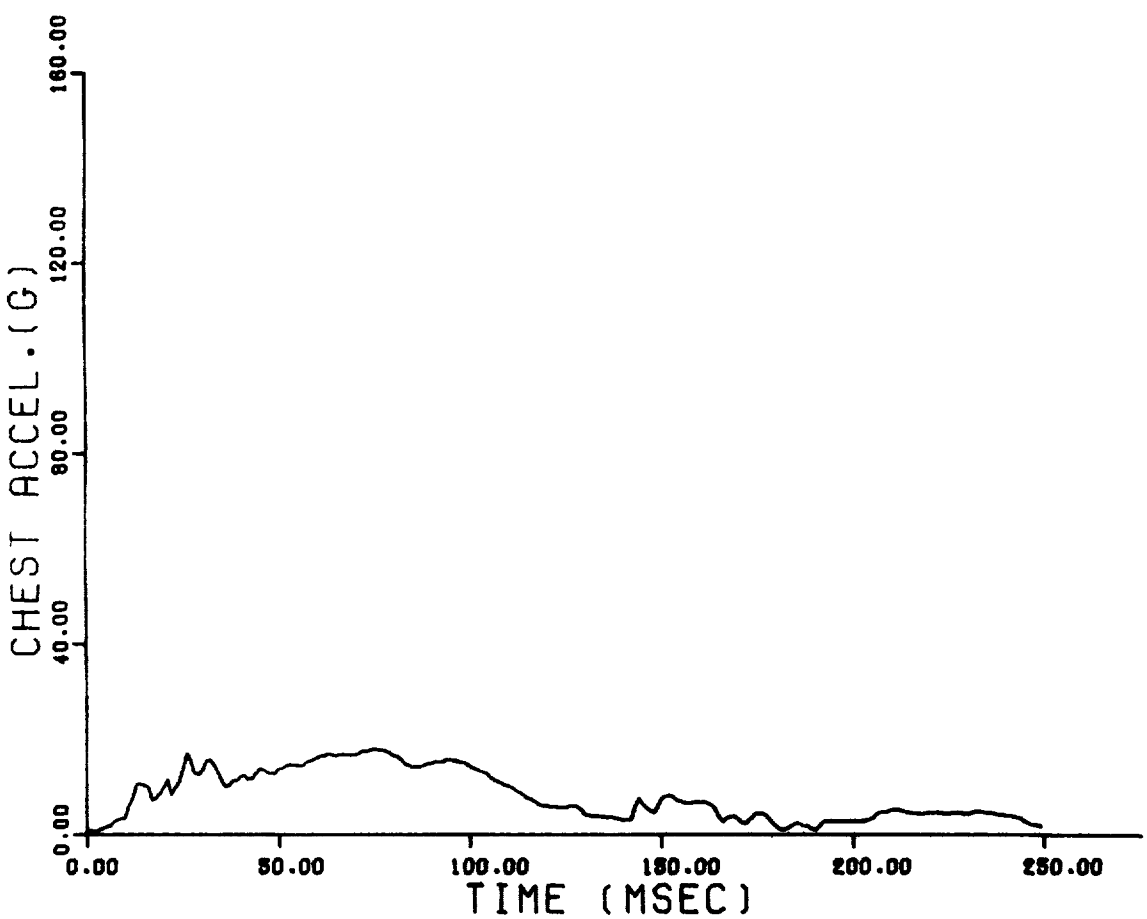
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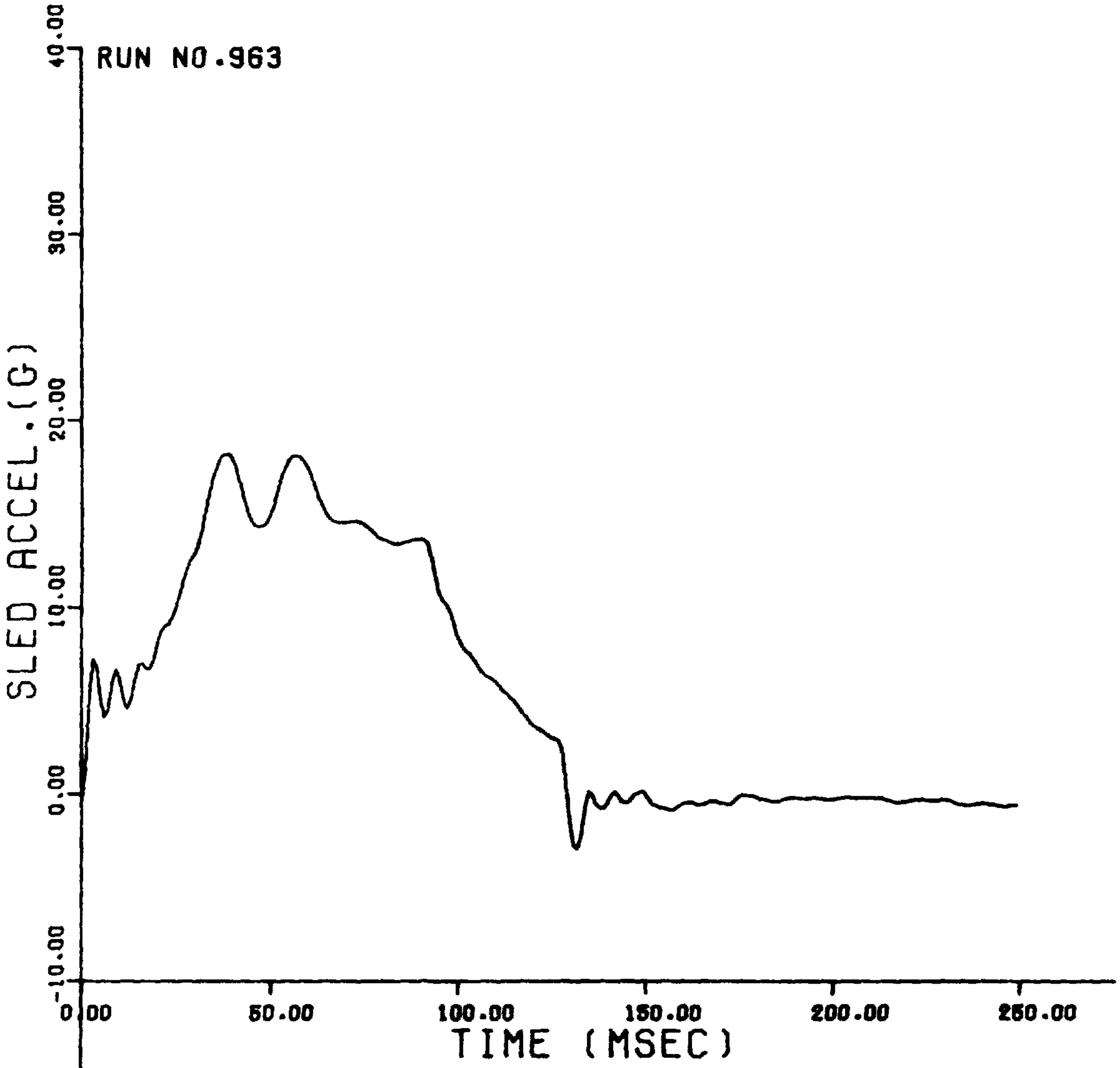
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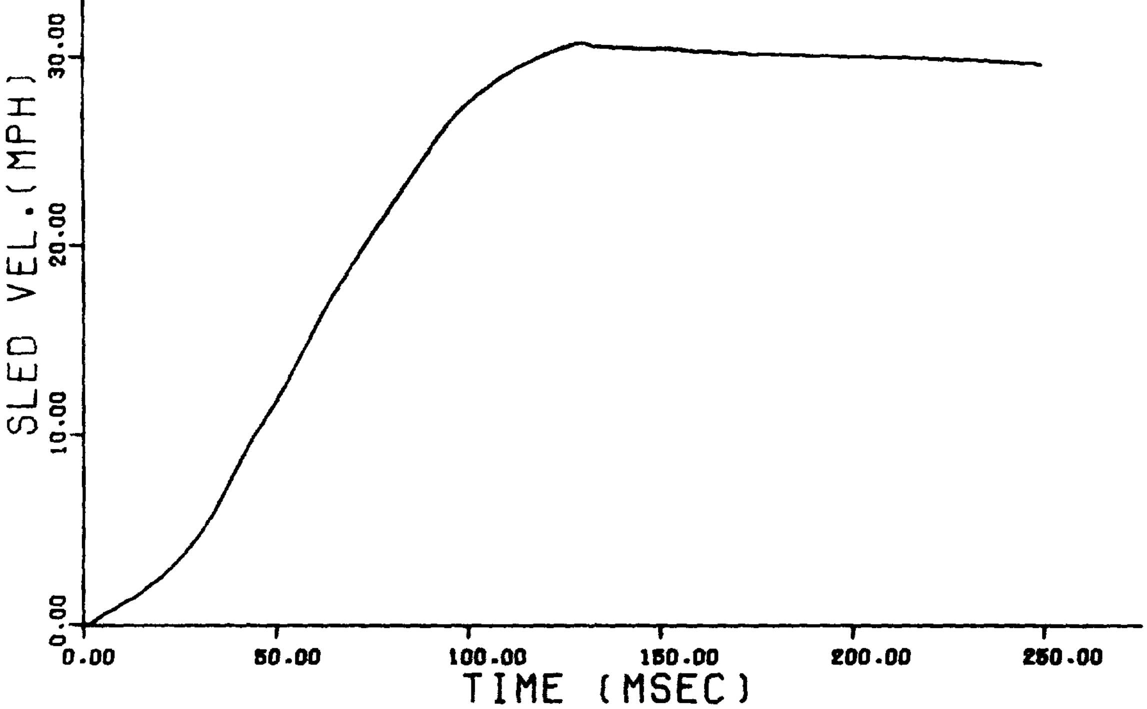
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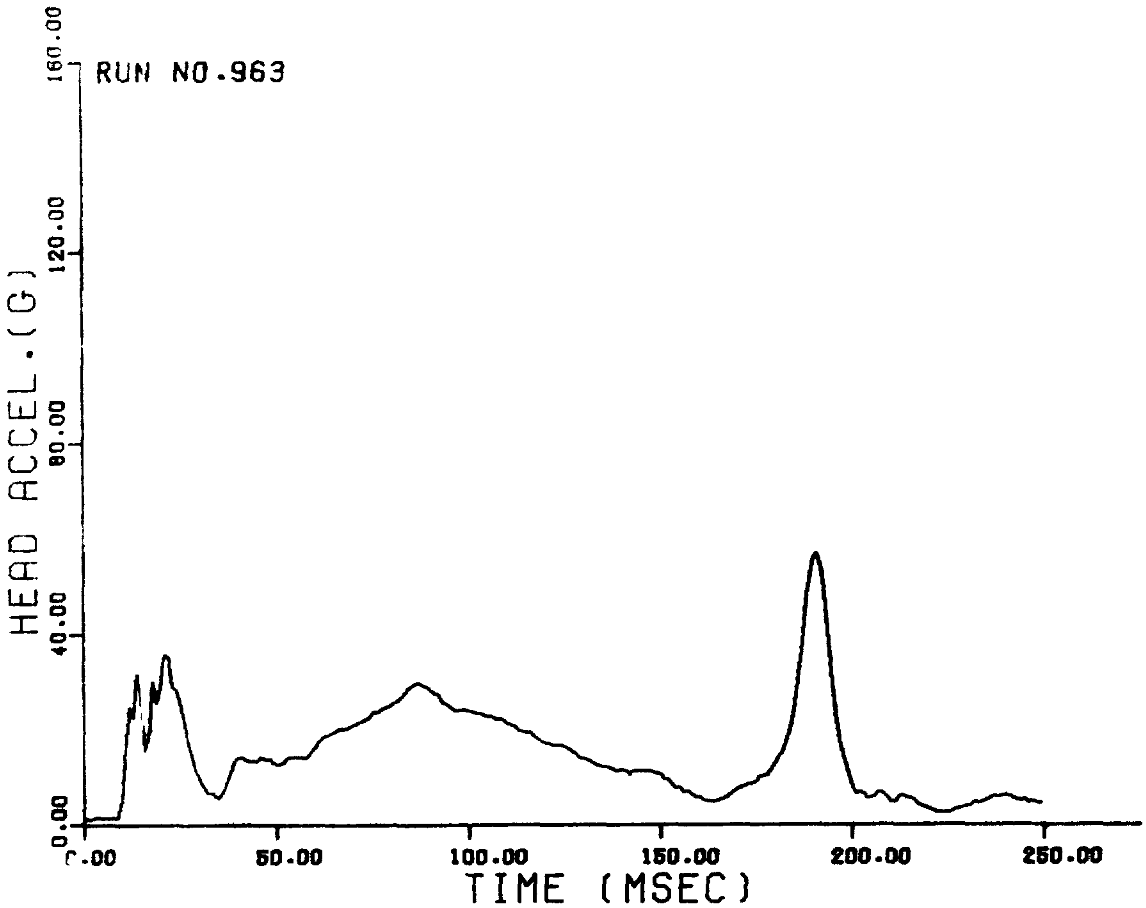
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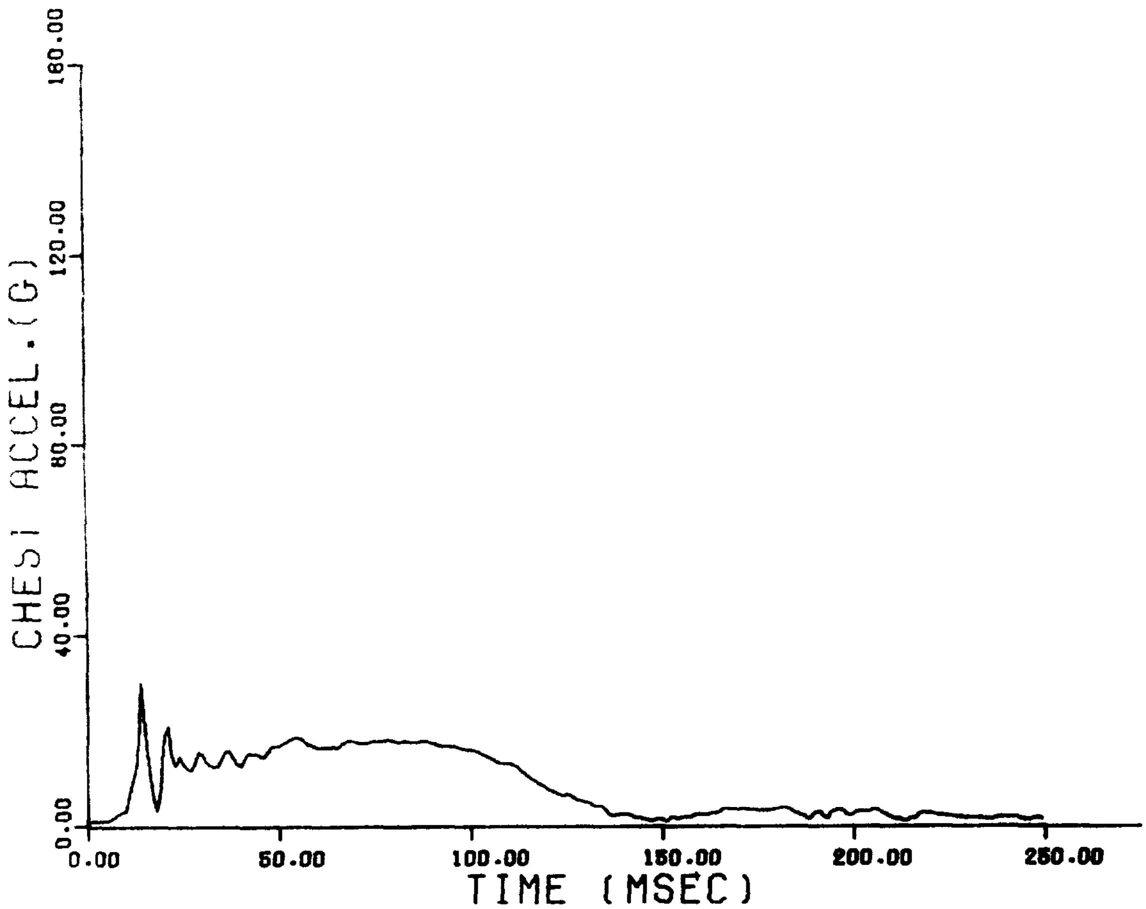
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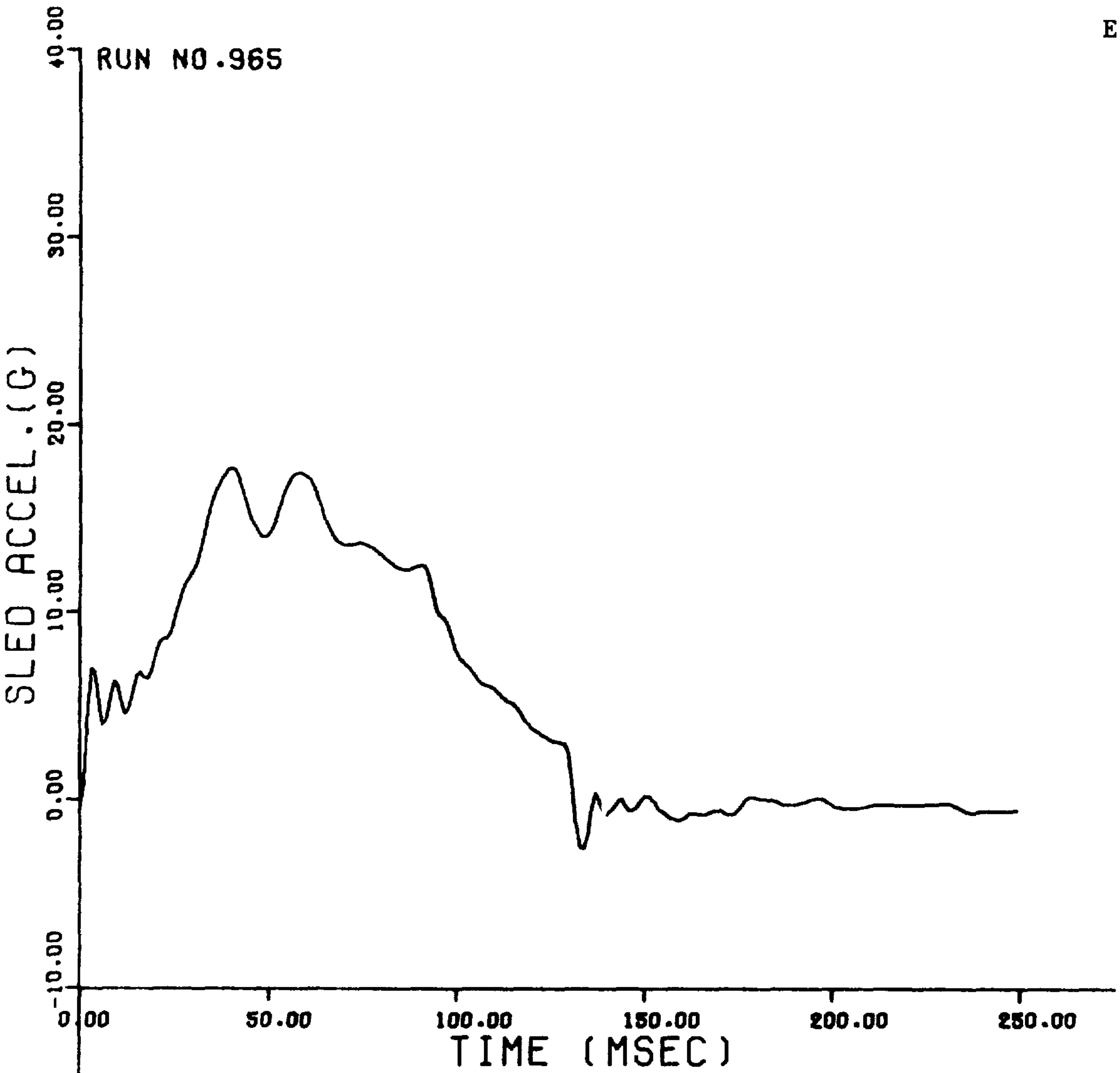
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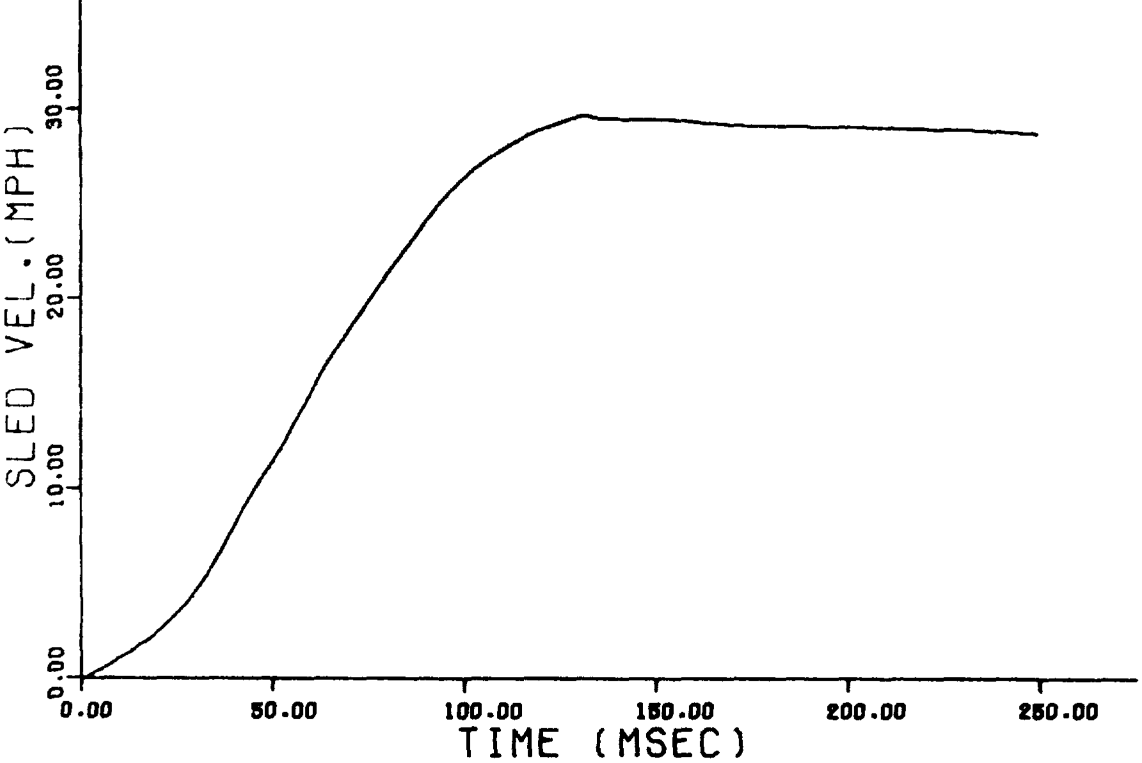
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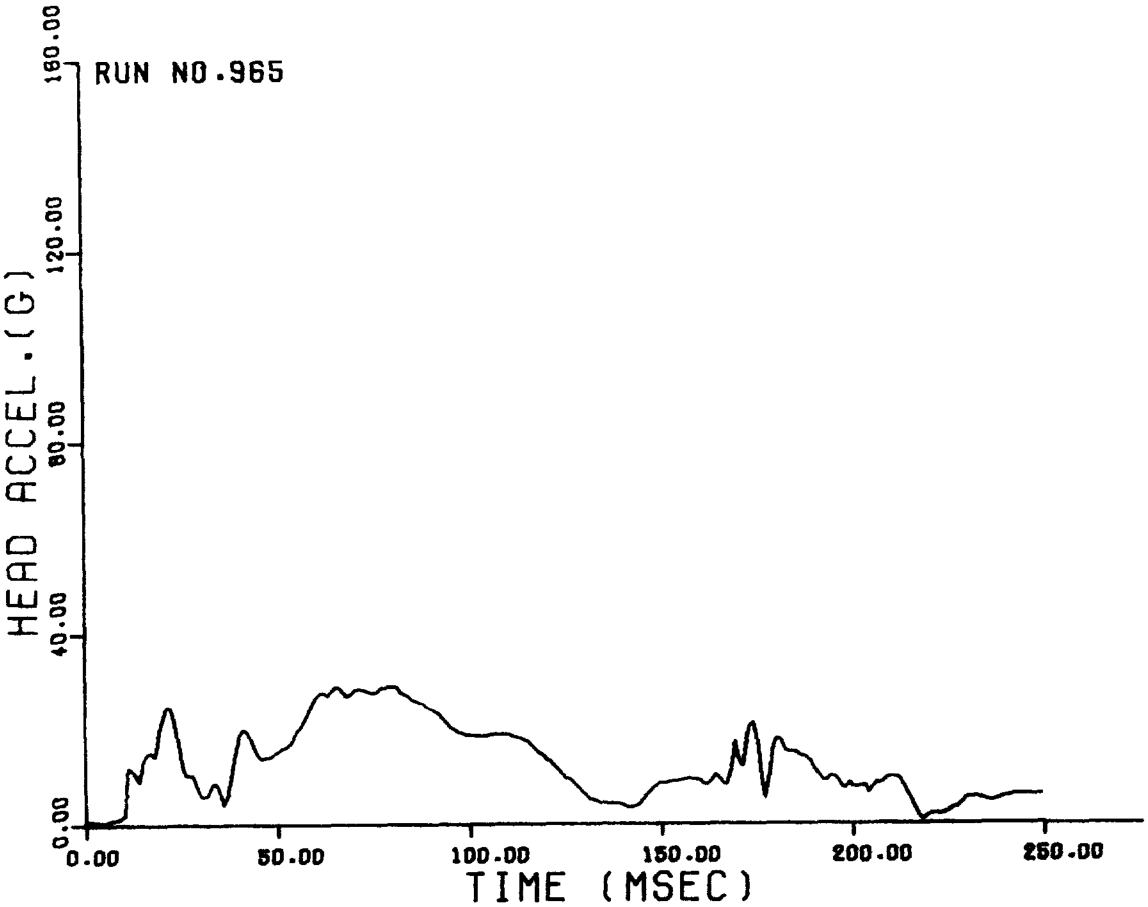
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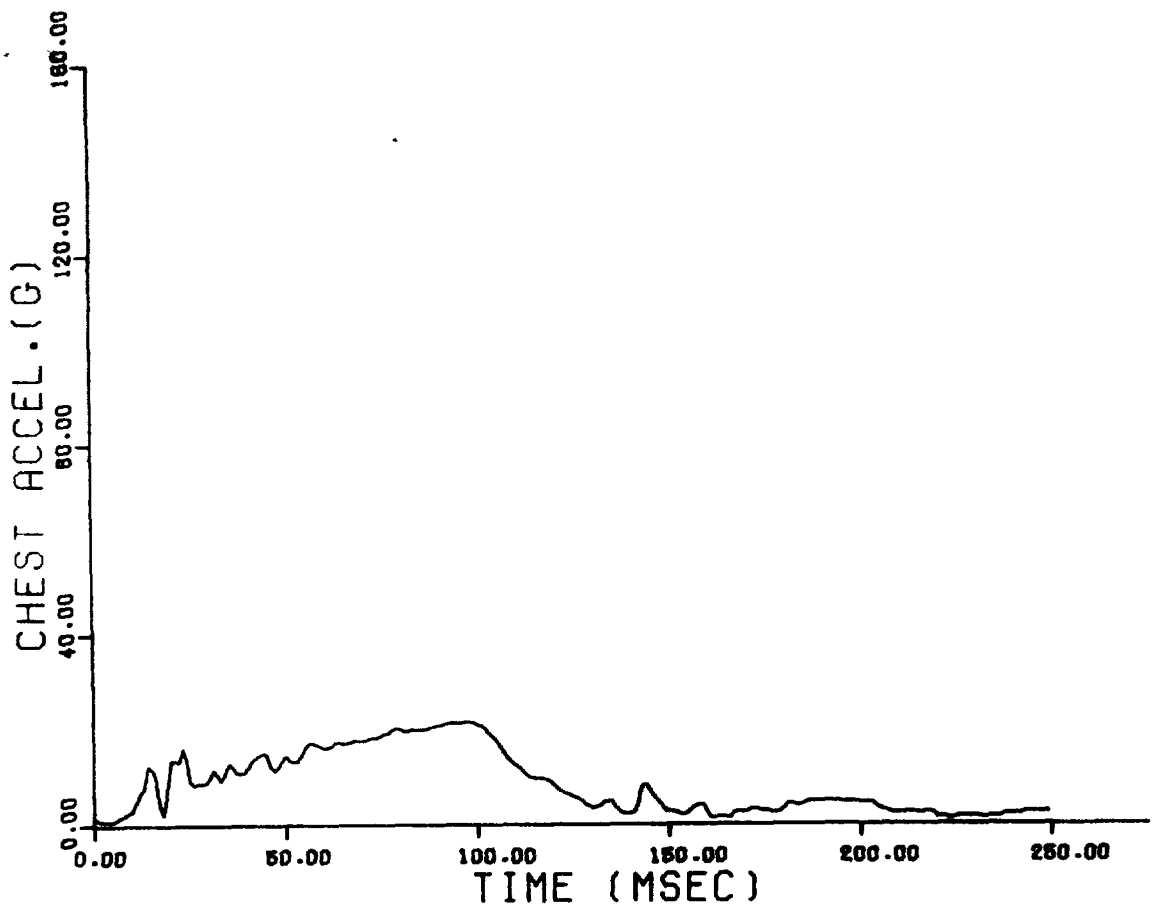
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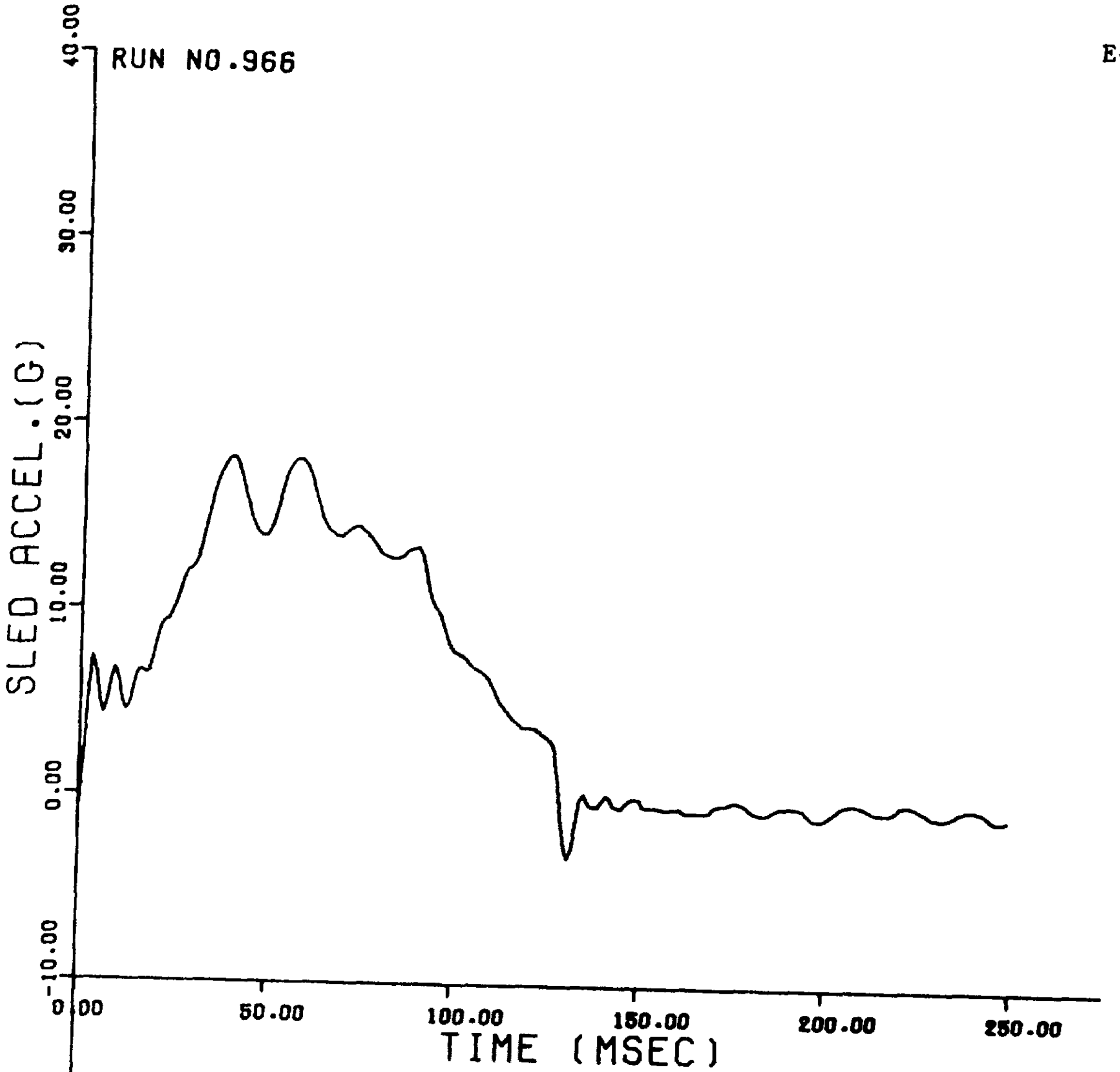
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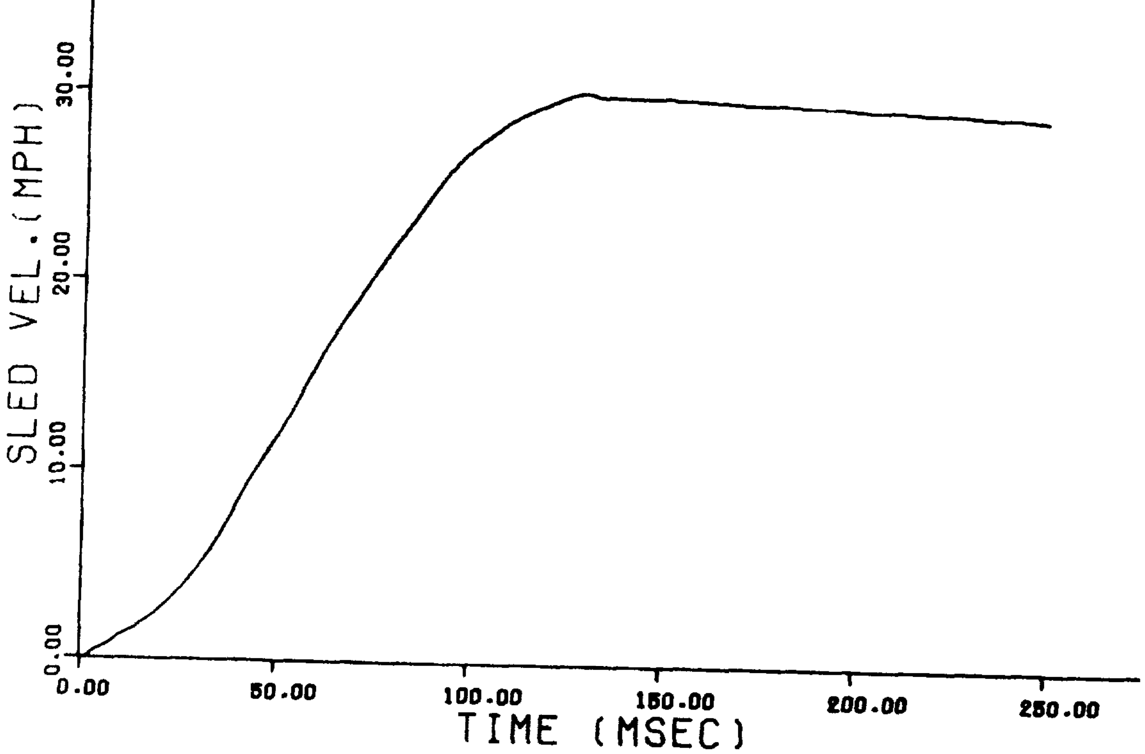
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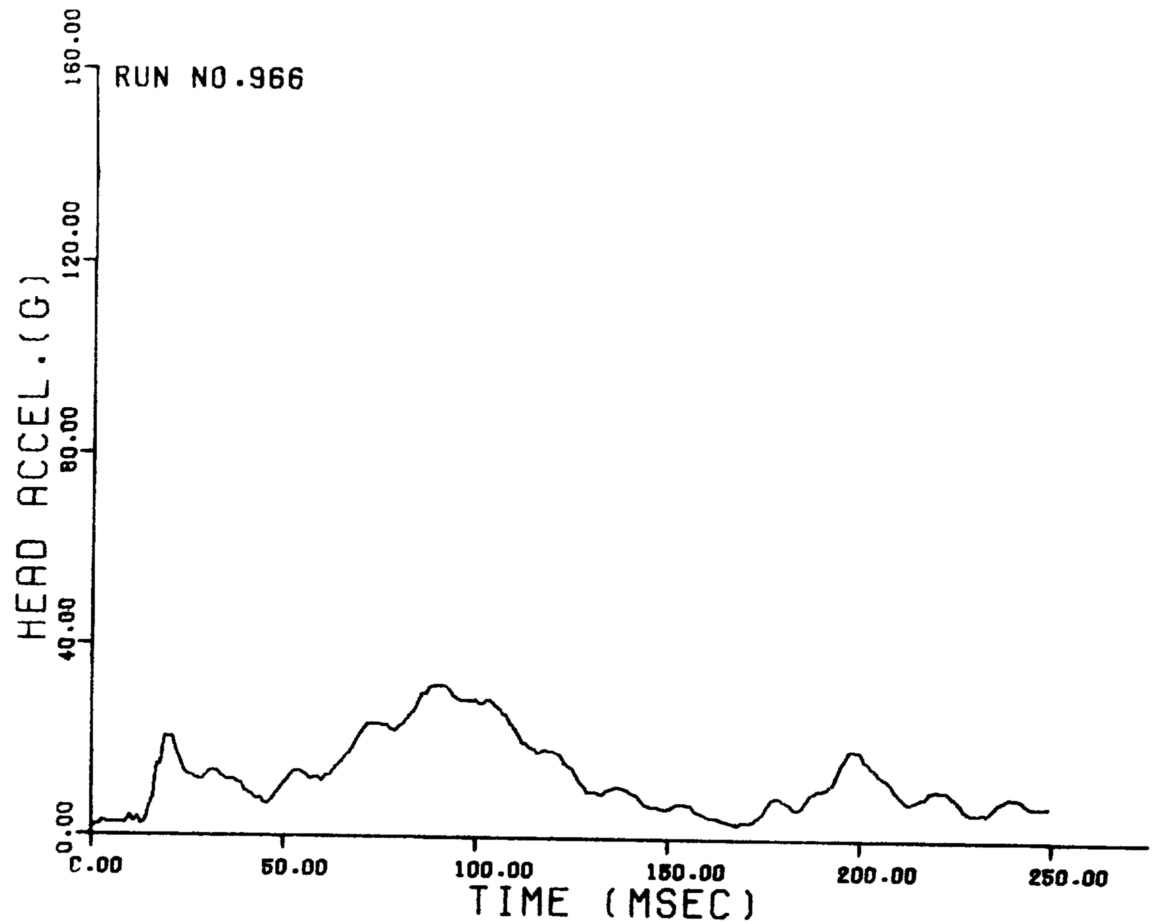
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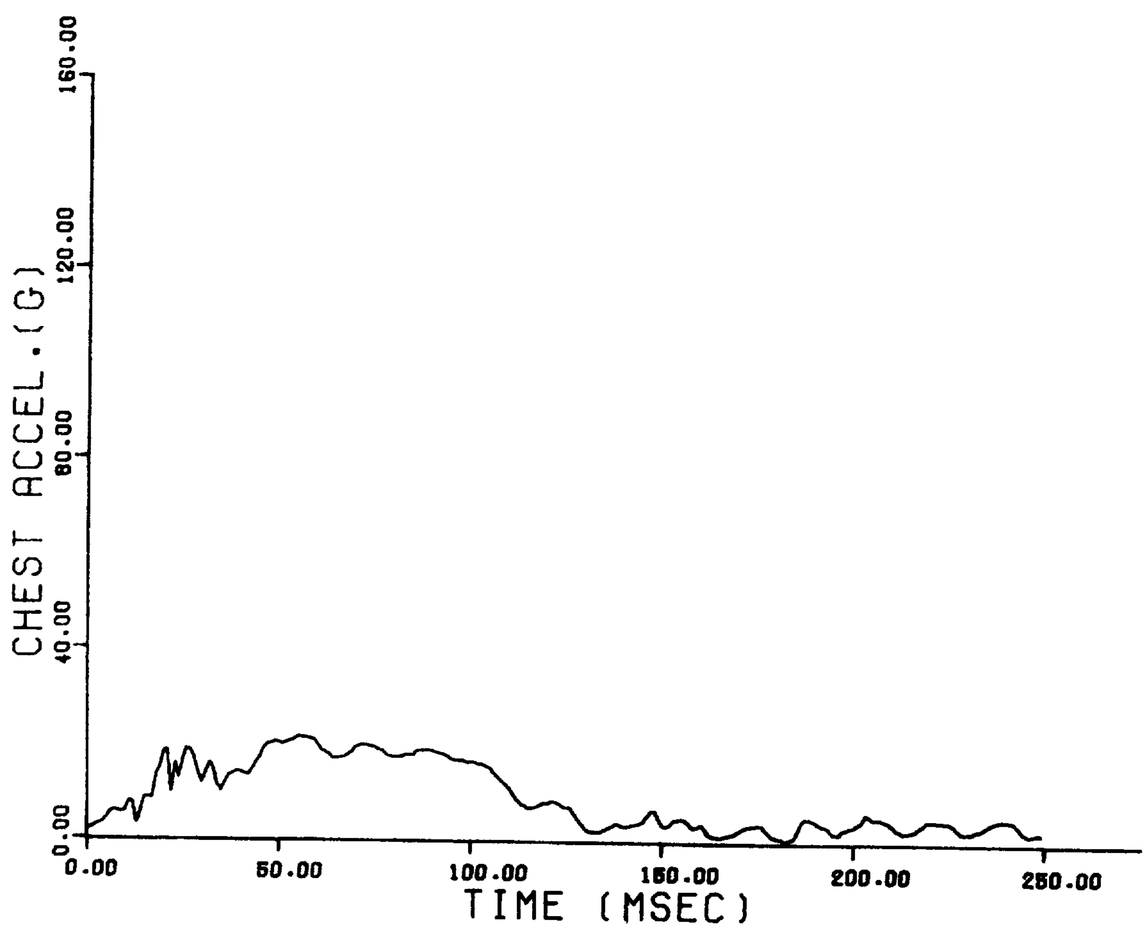
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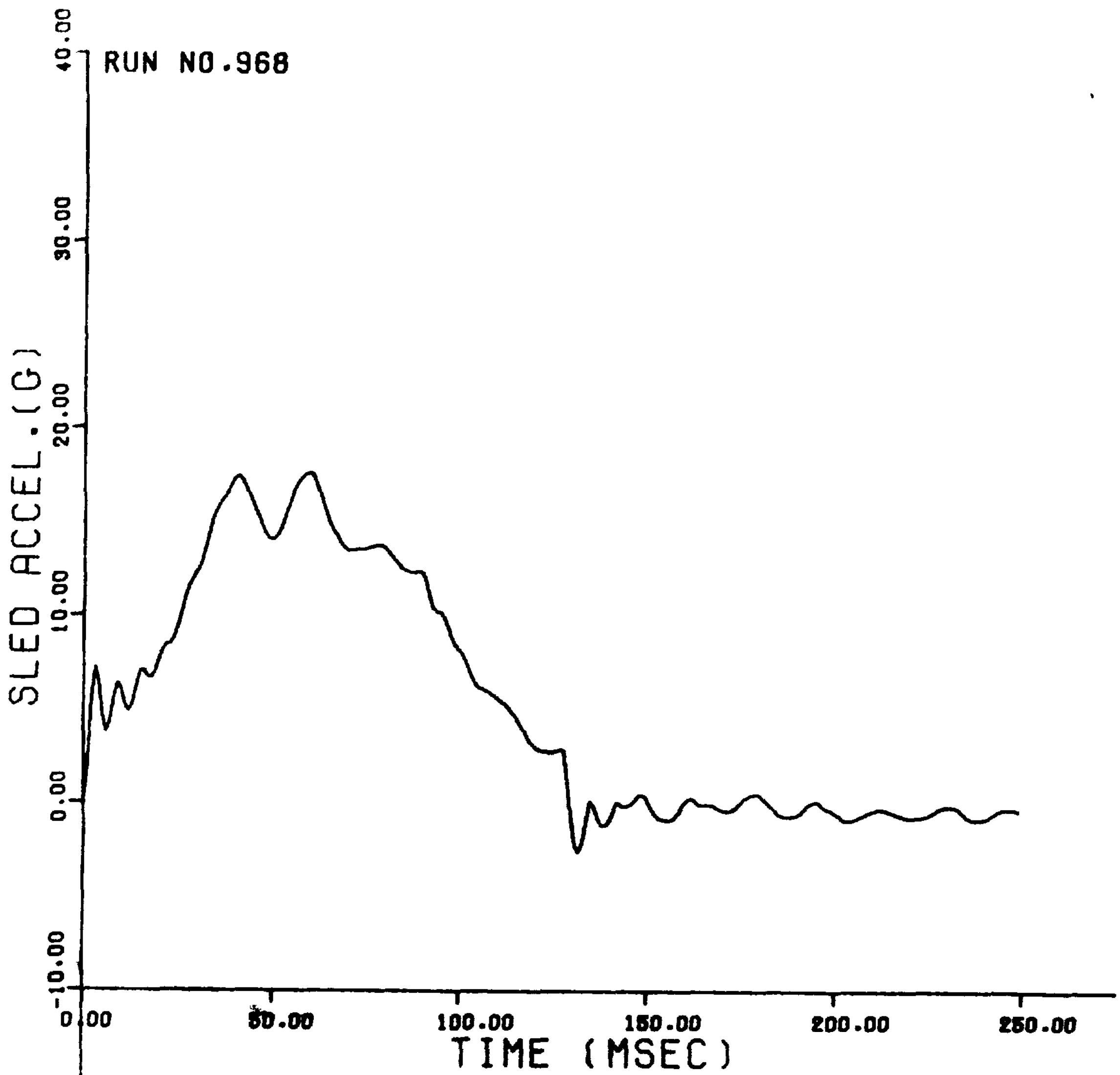
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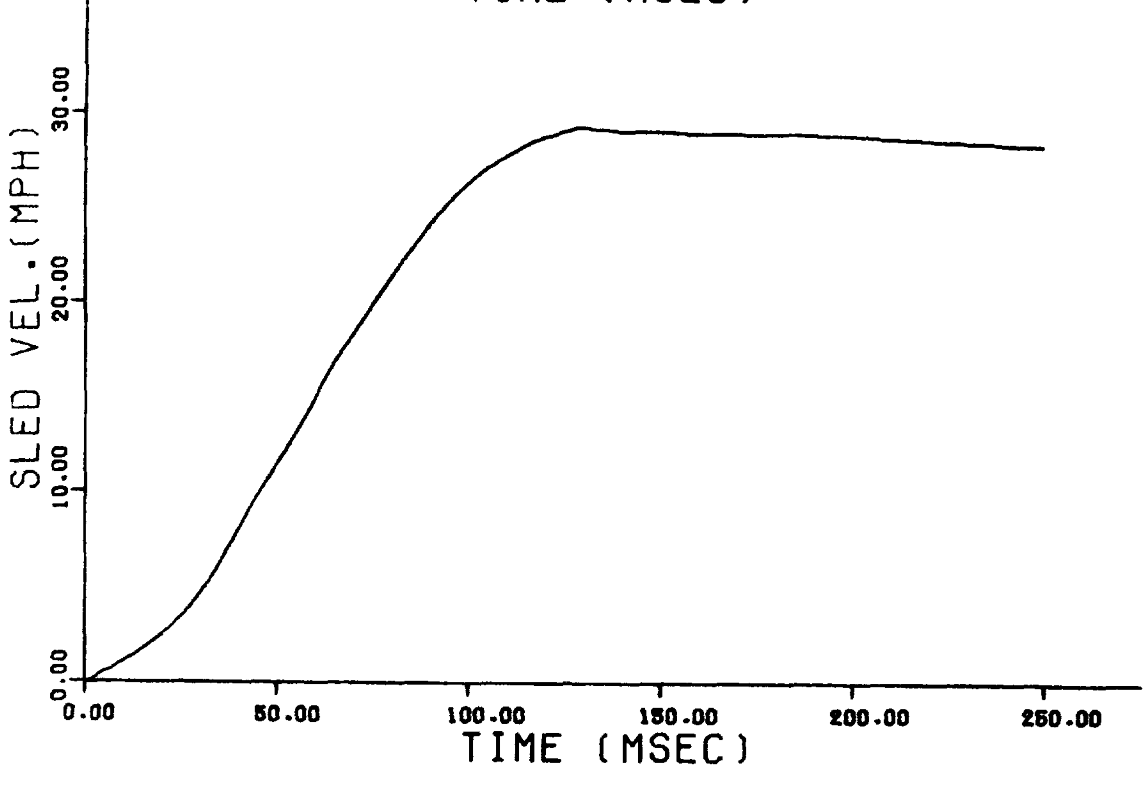
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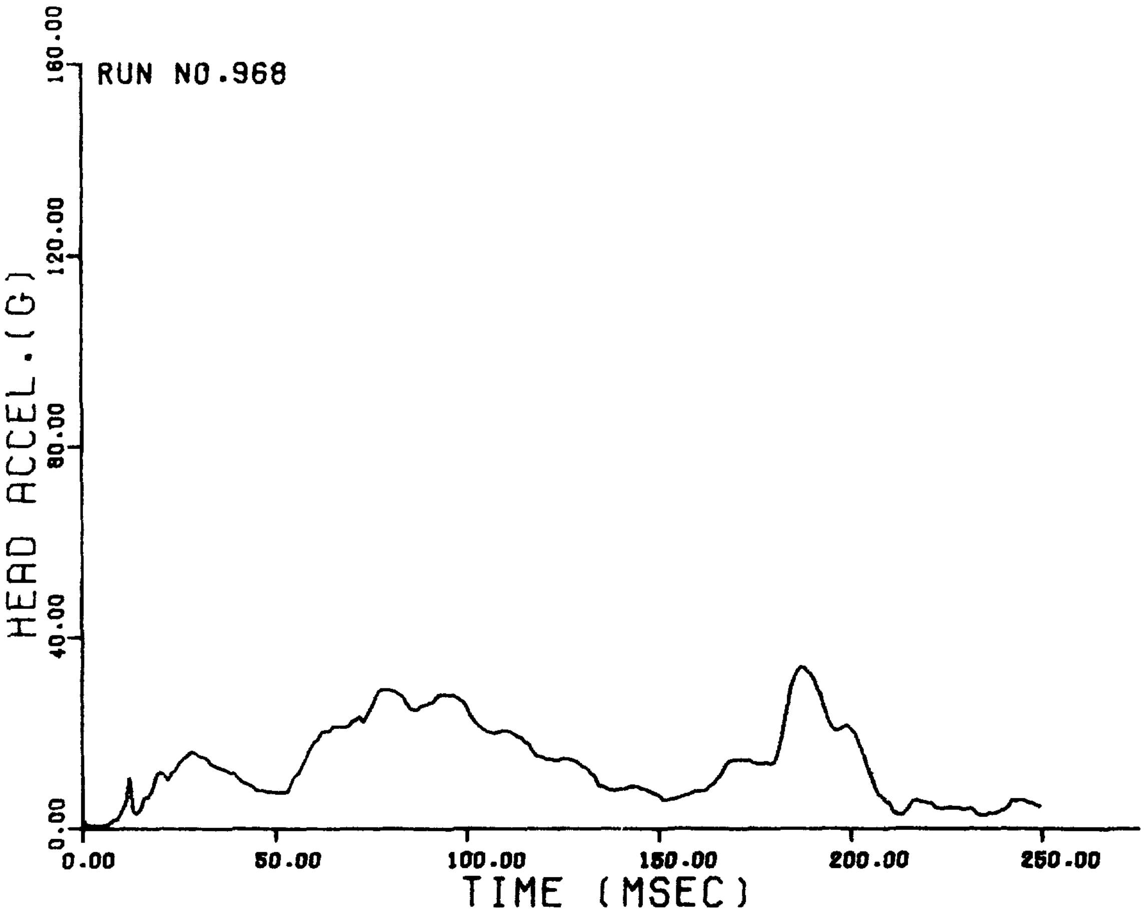
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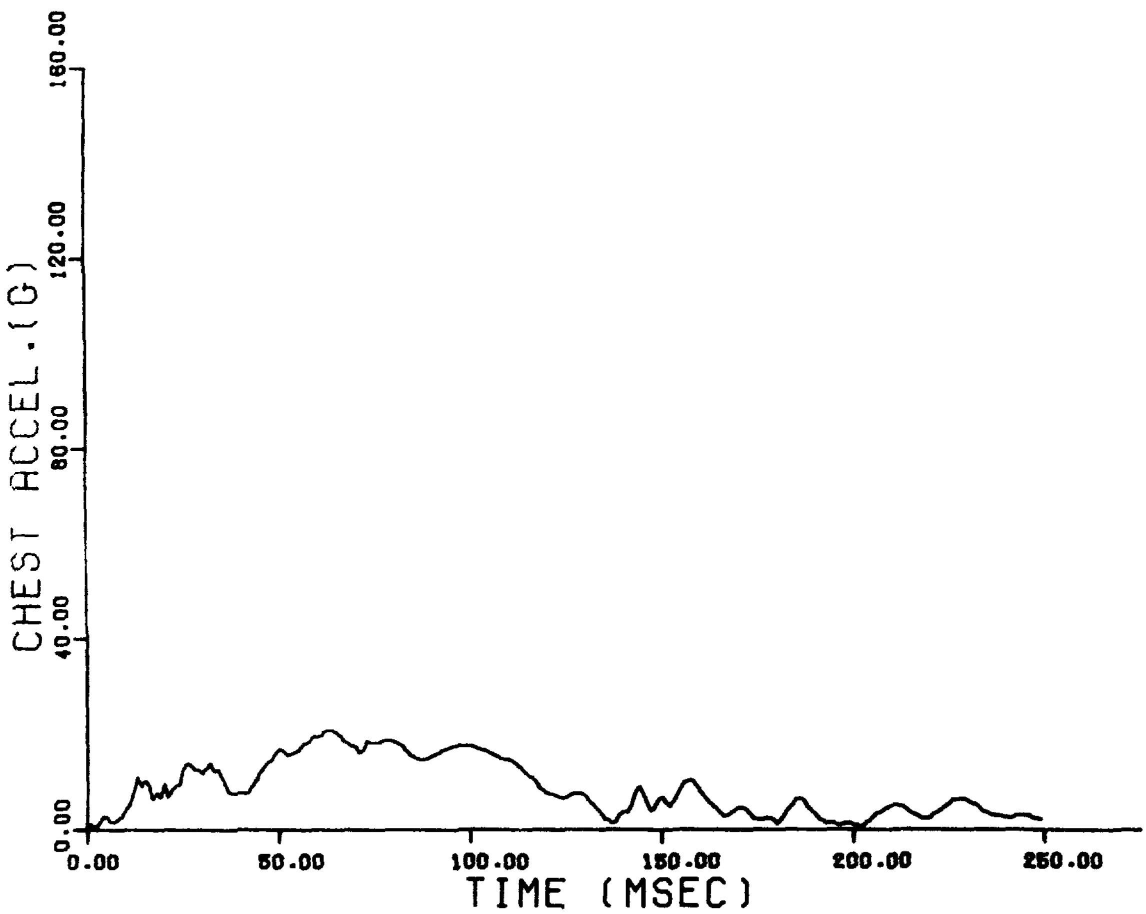
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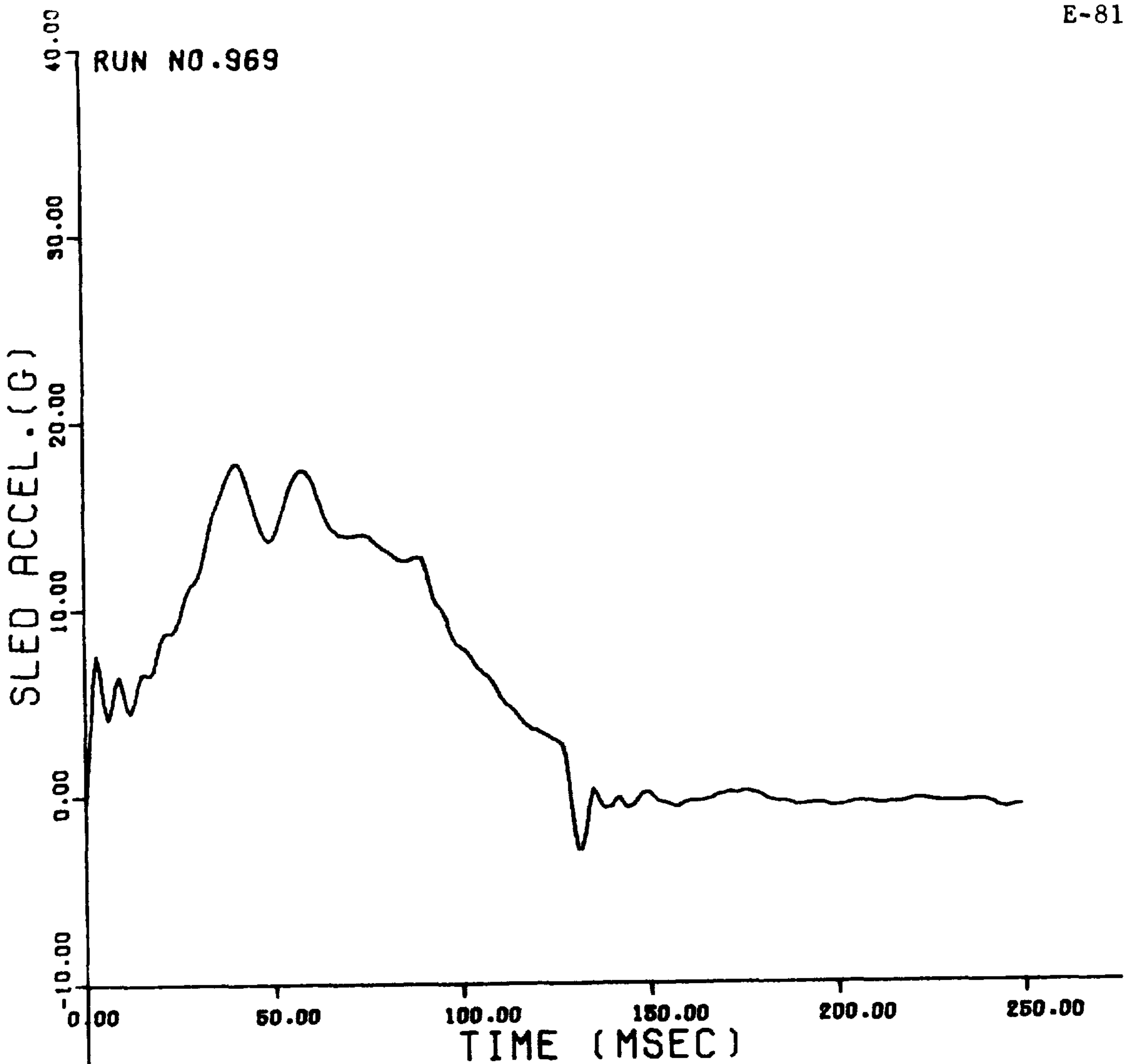
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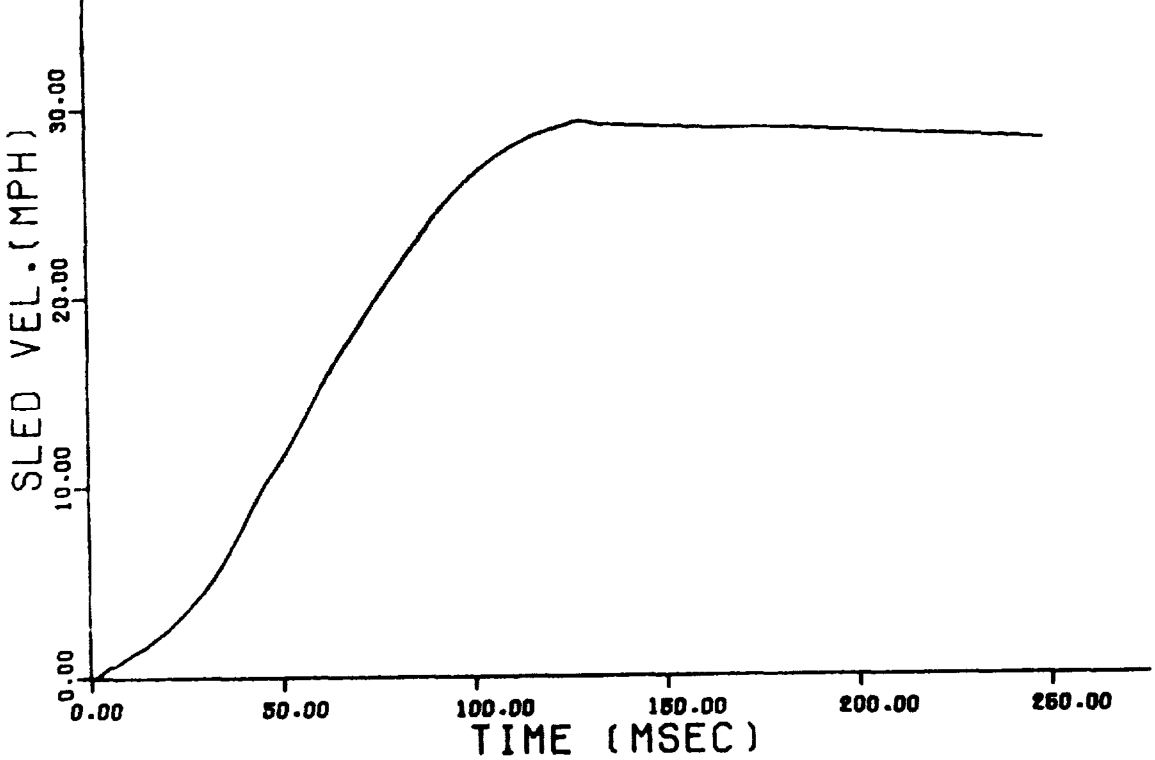
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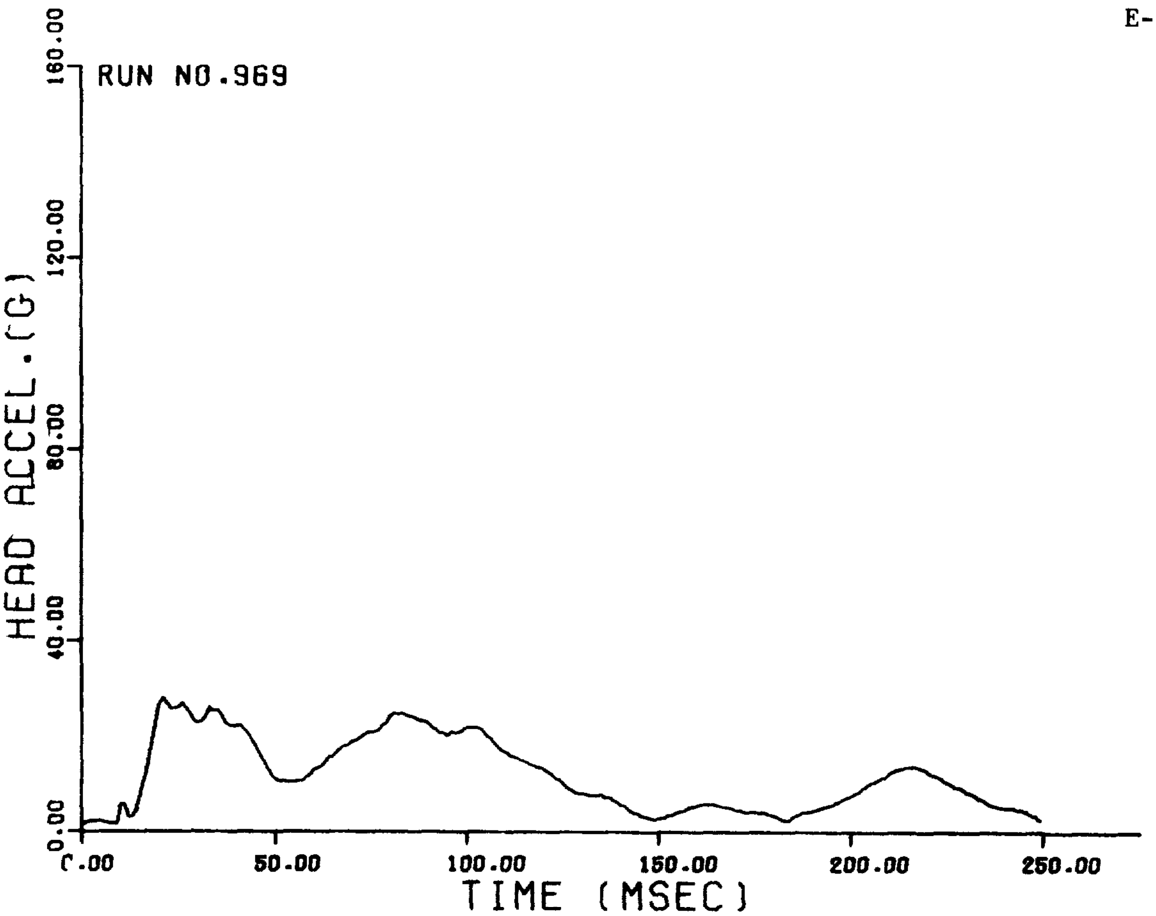
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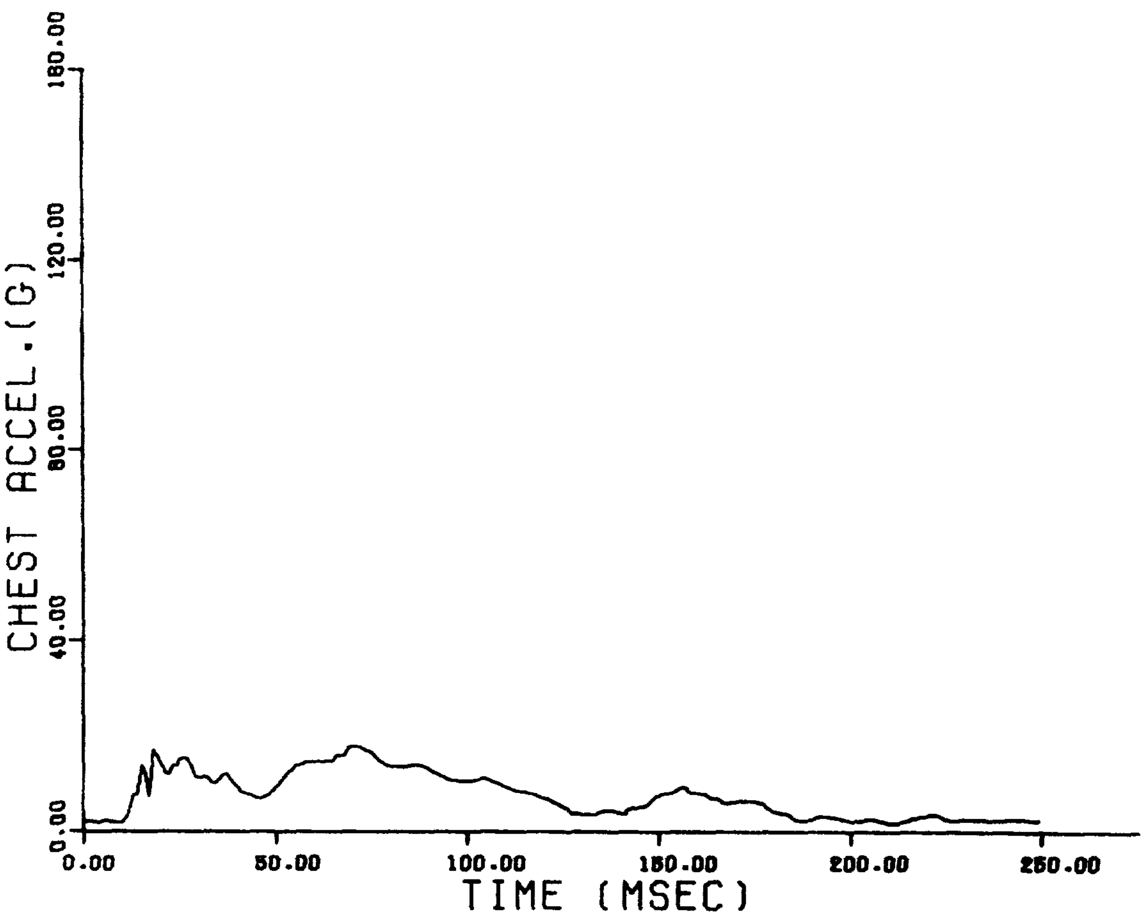
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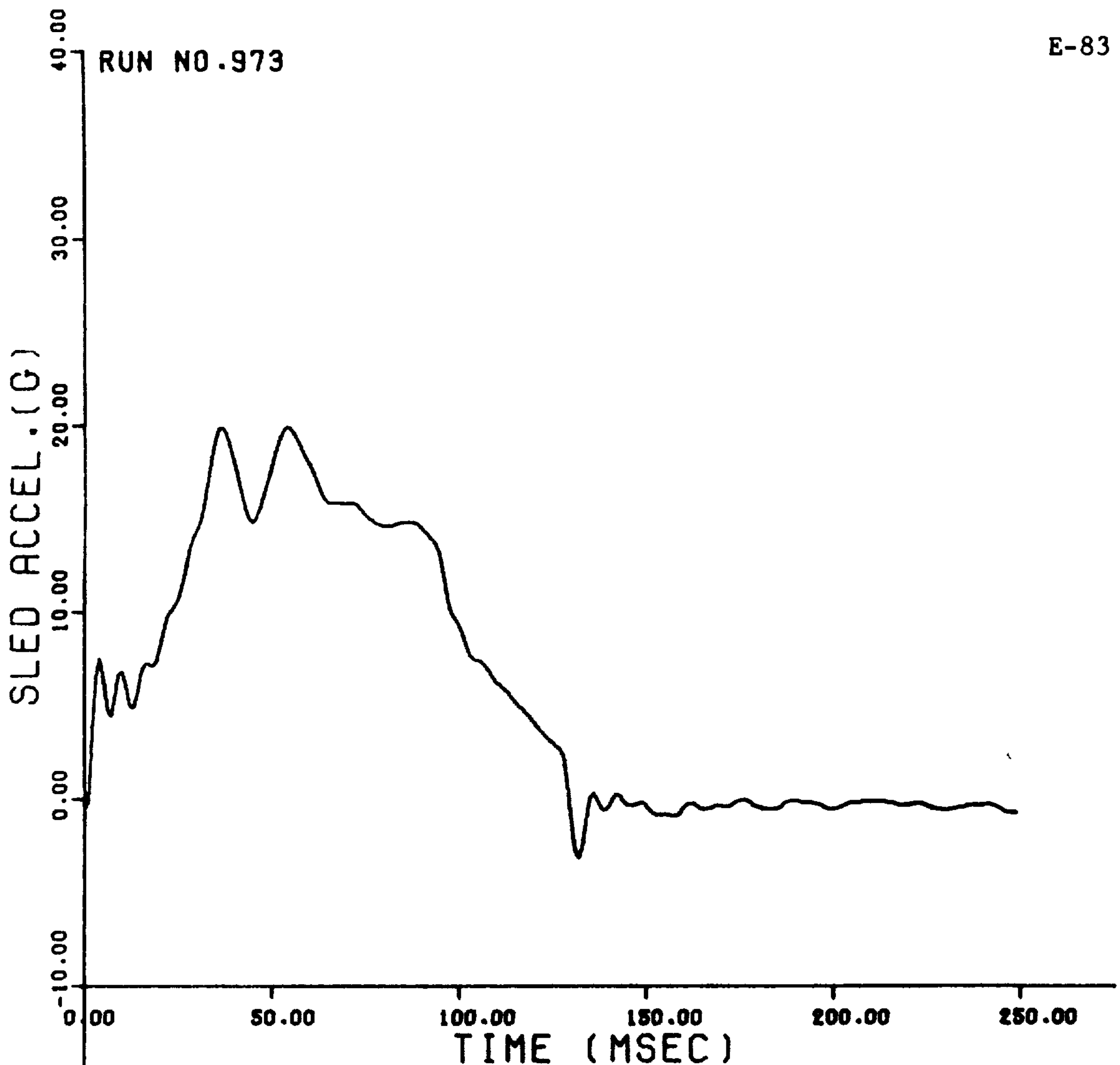
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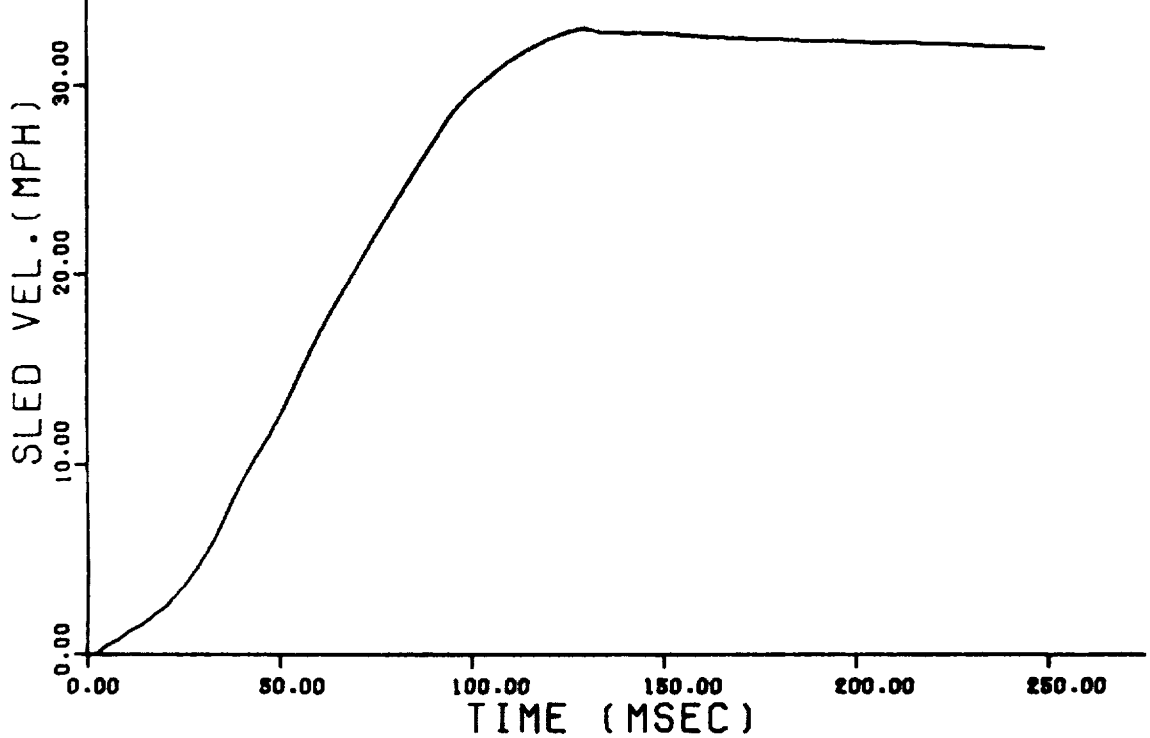
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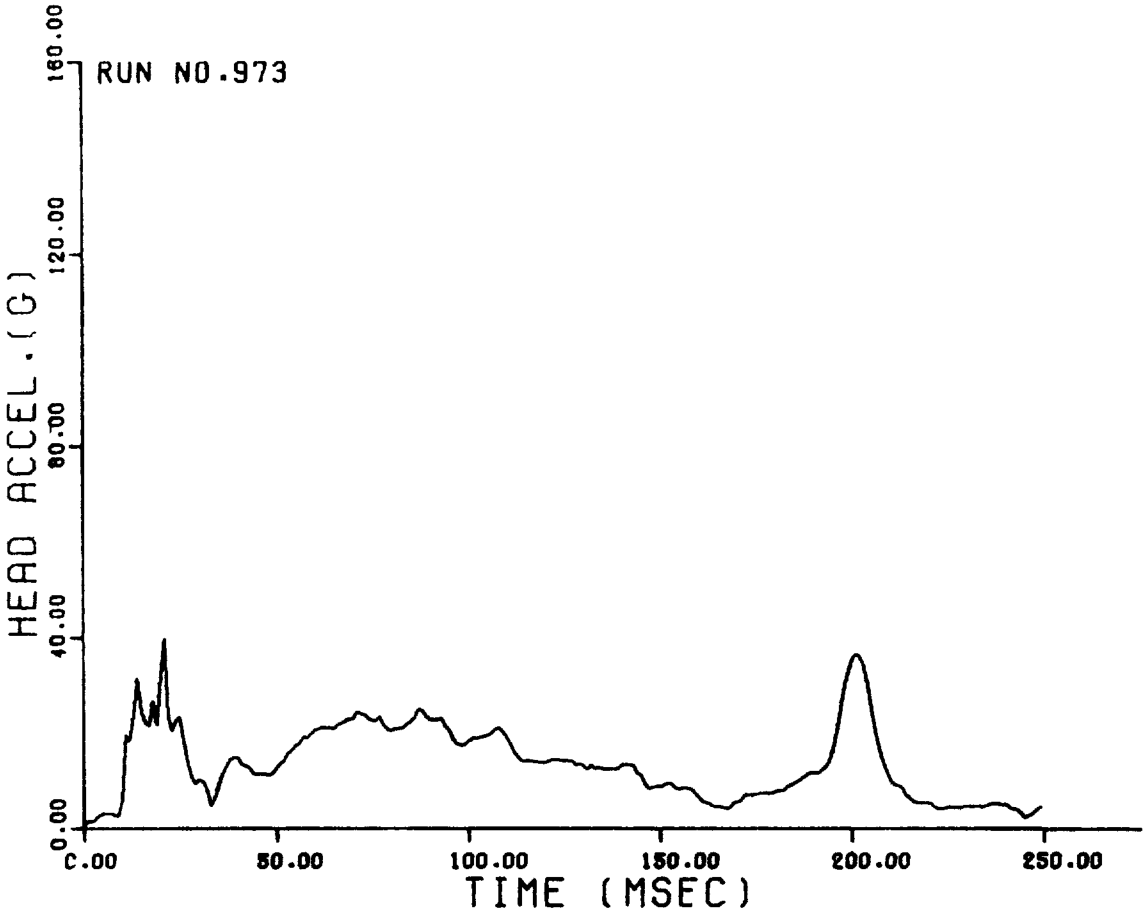
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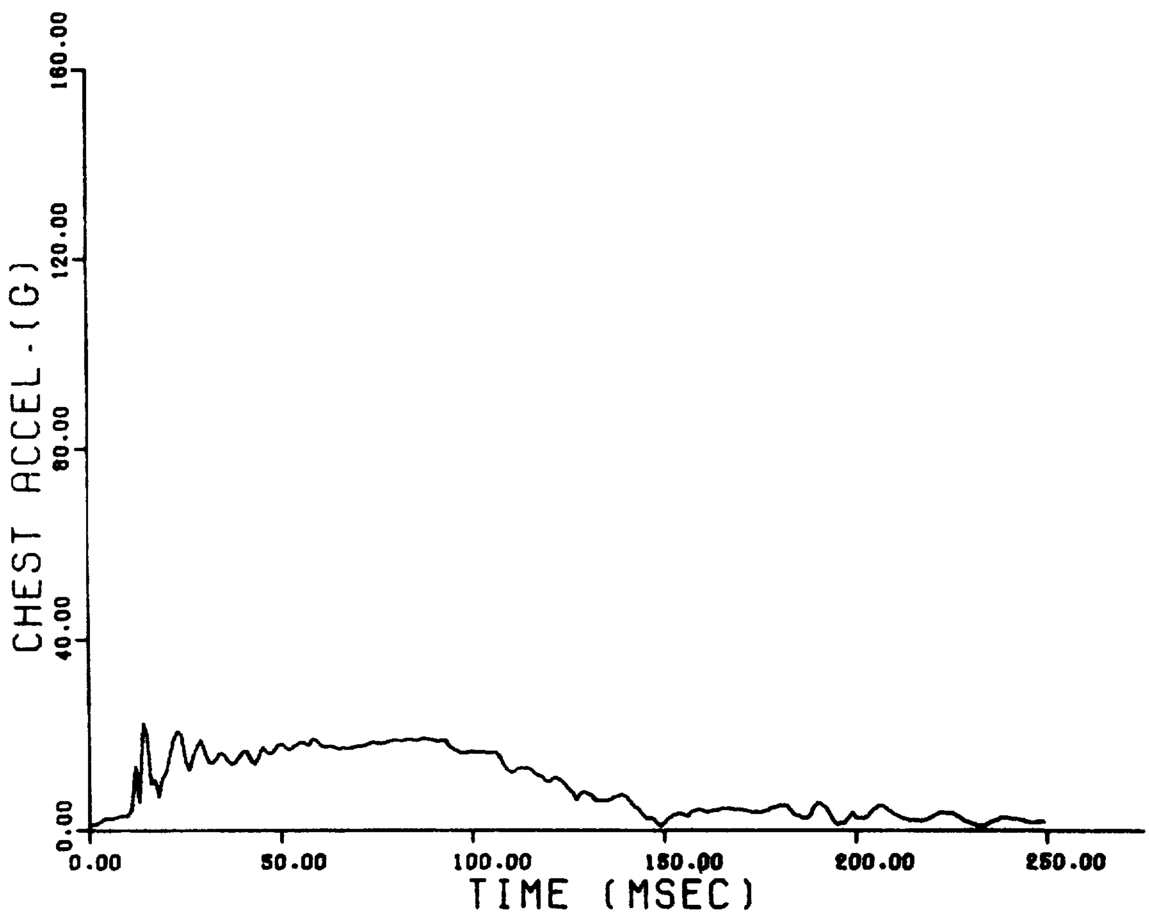
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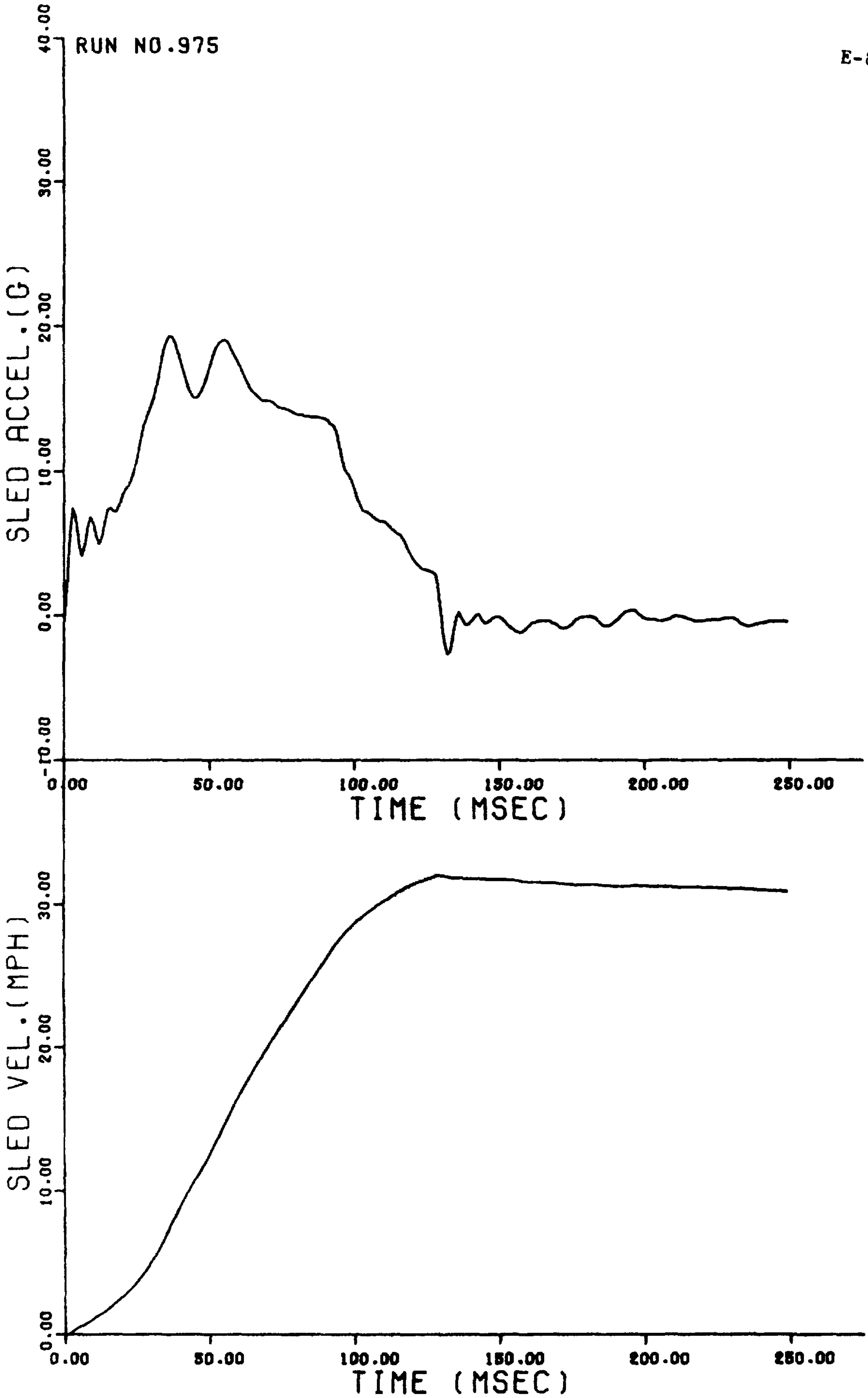
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TIME (MSEC)
SLED VEL.(MPH)
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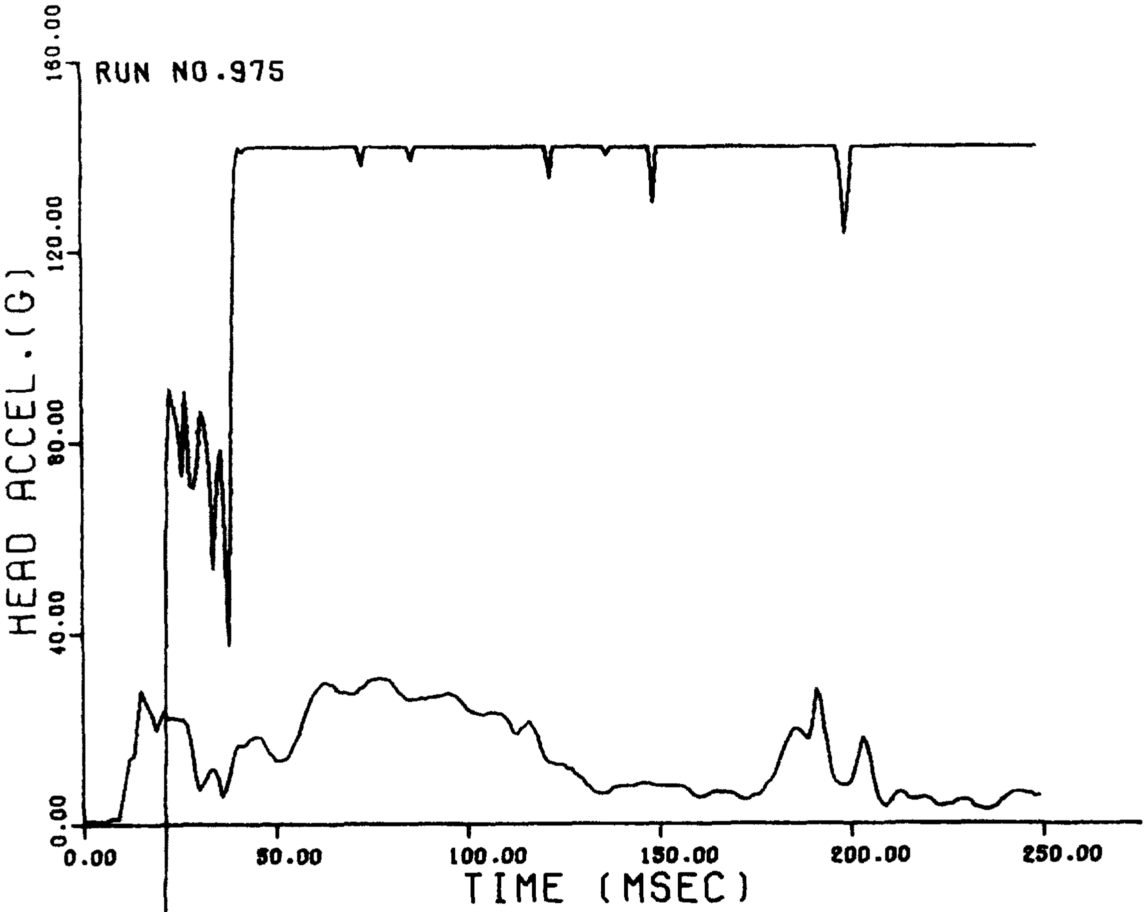
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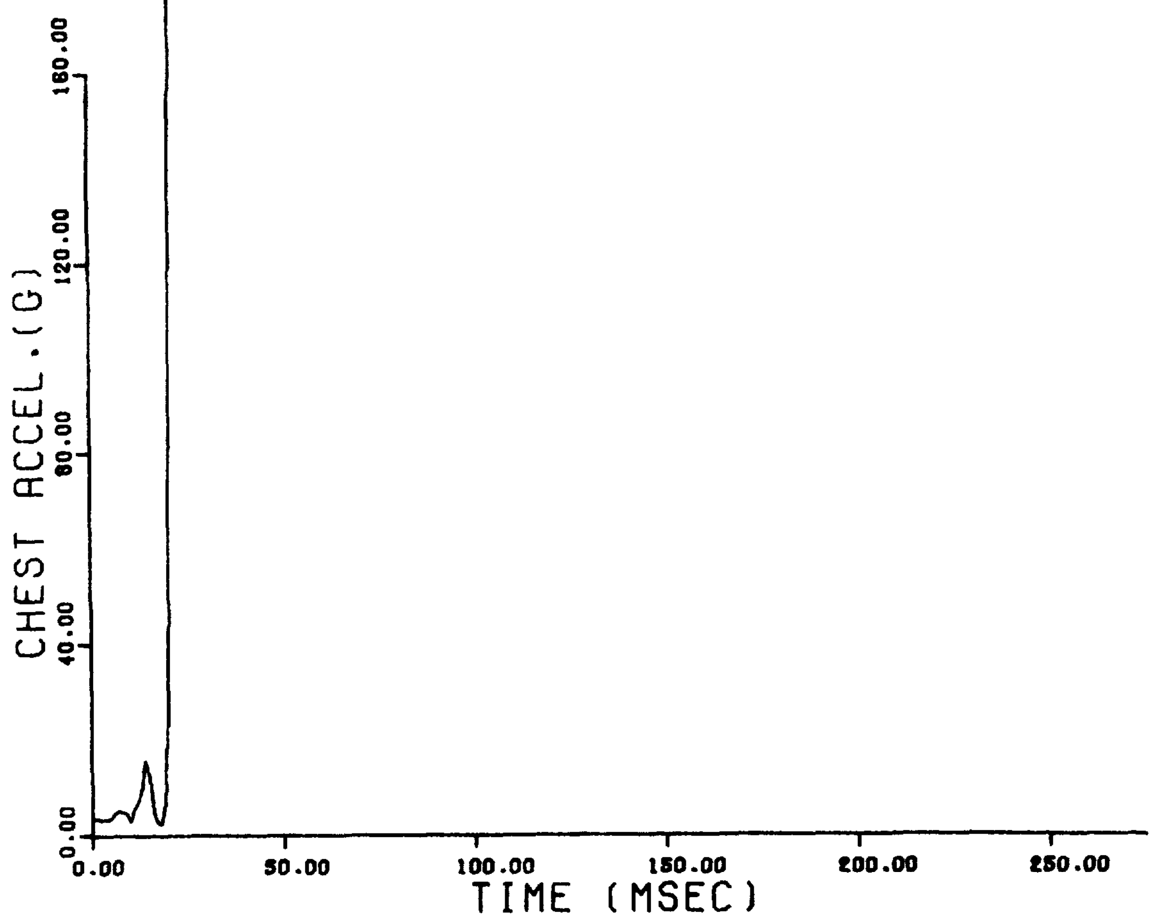
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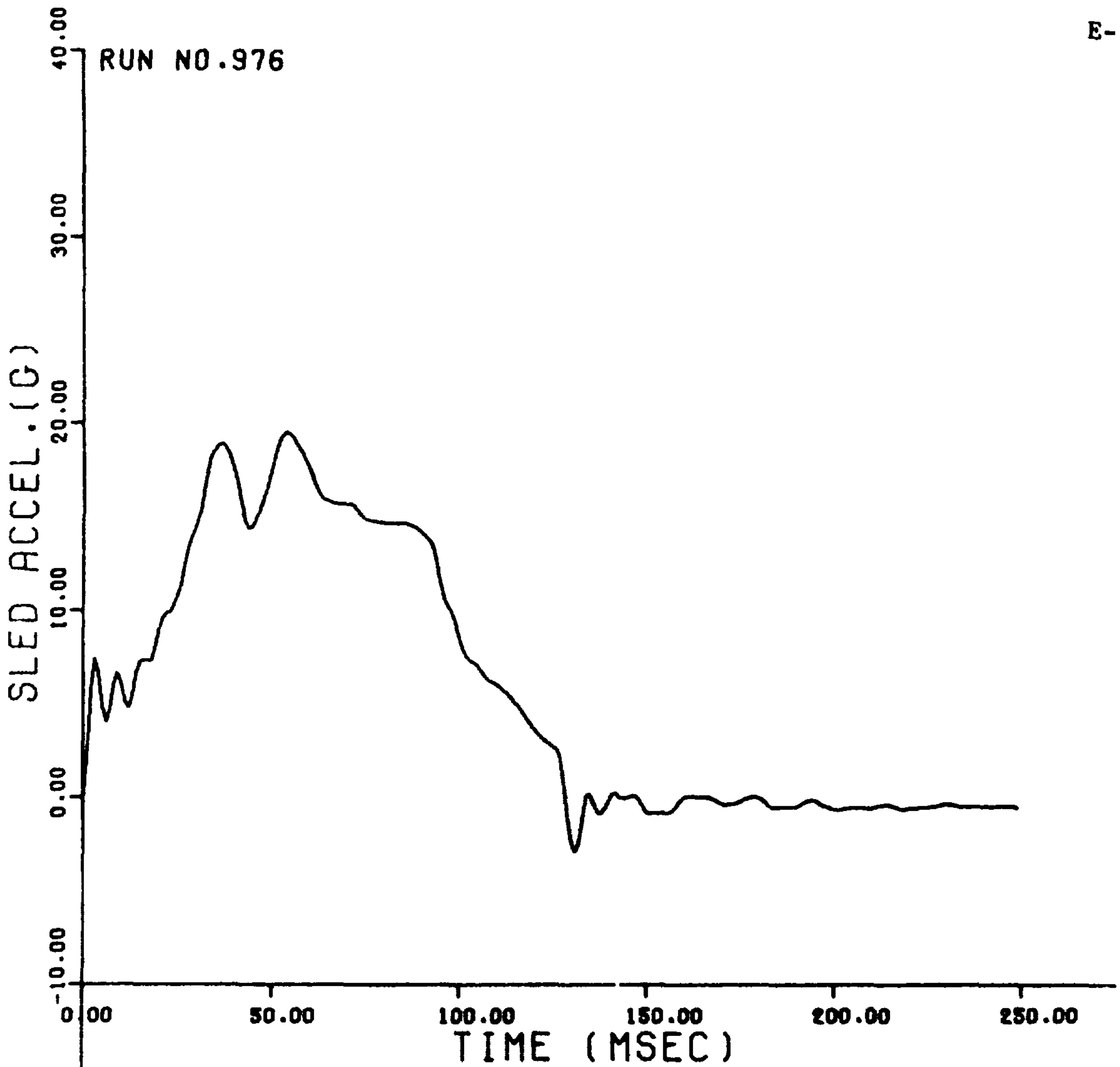
TIME (MSEC)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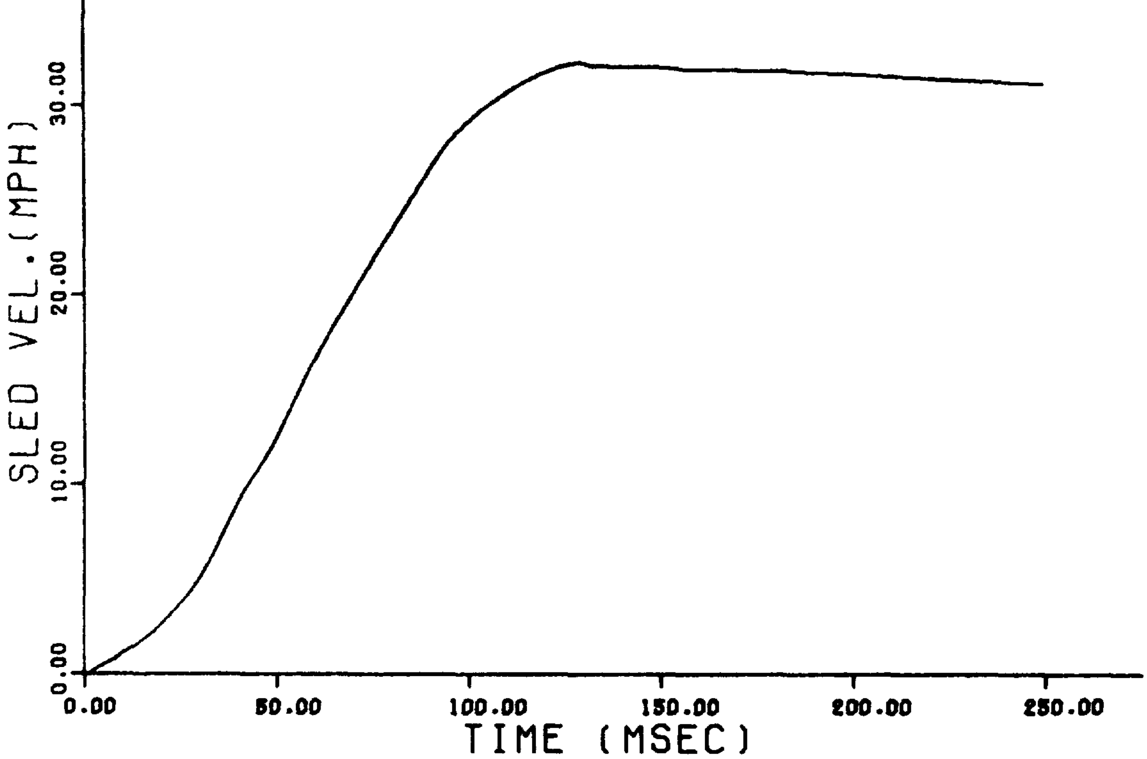
TIME (MSEC)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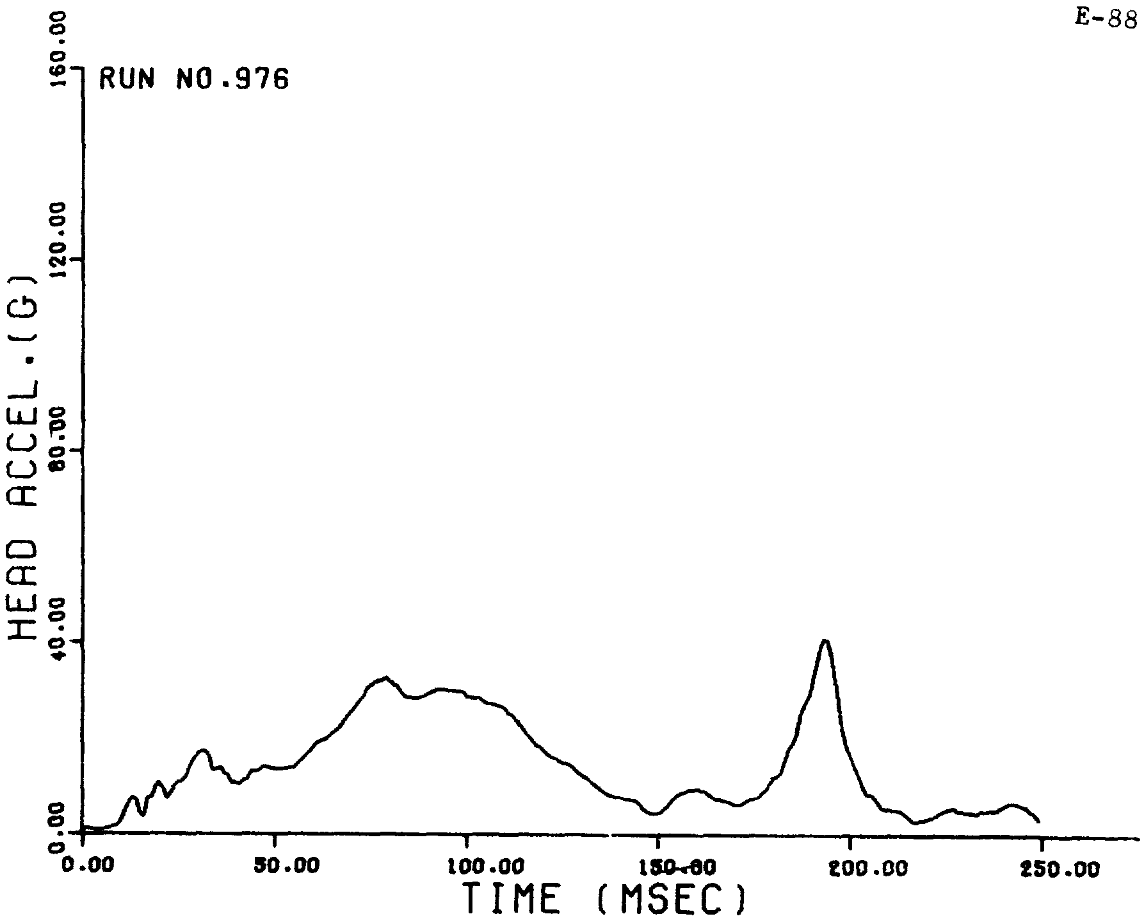
TIME (MSEC)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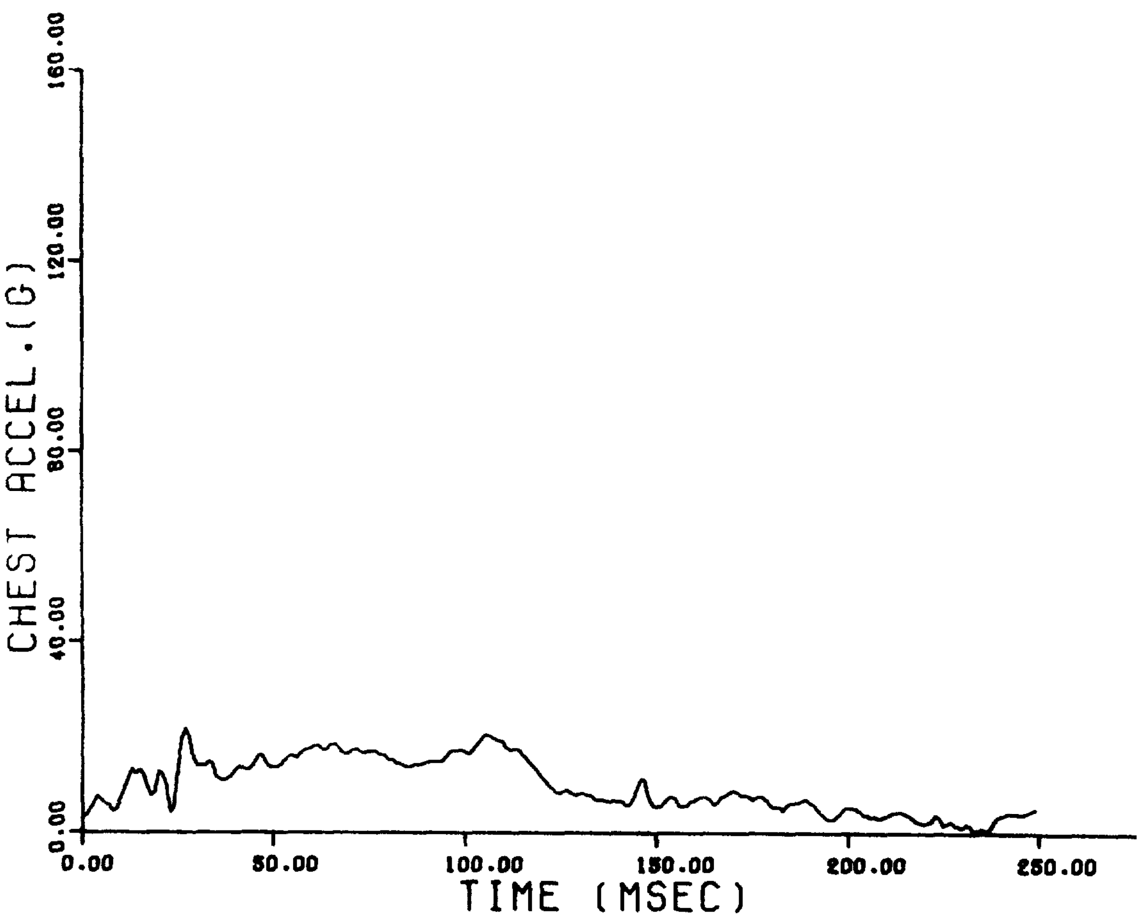
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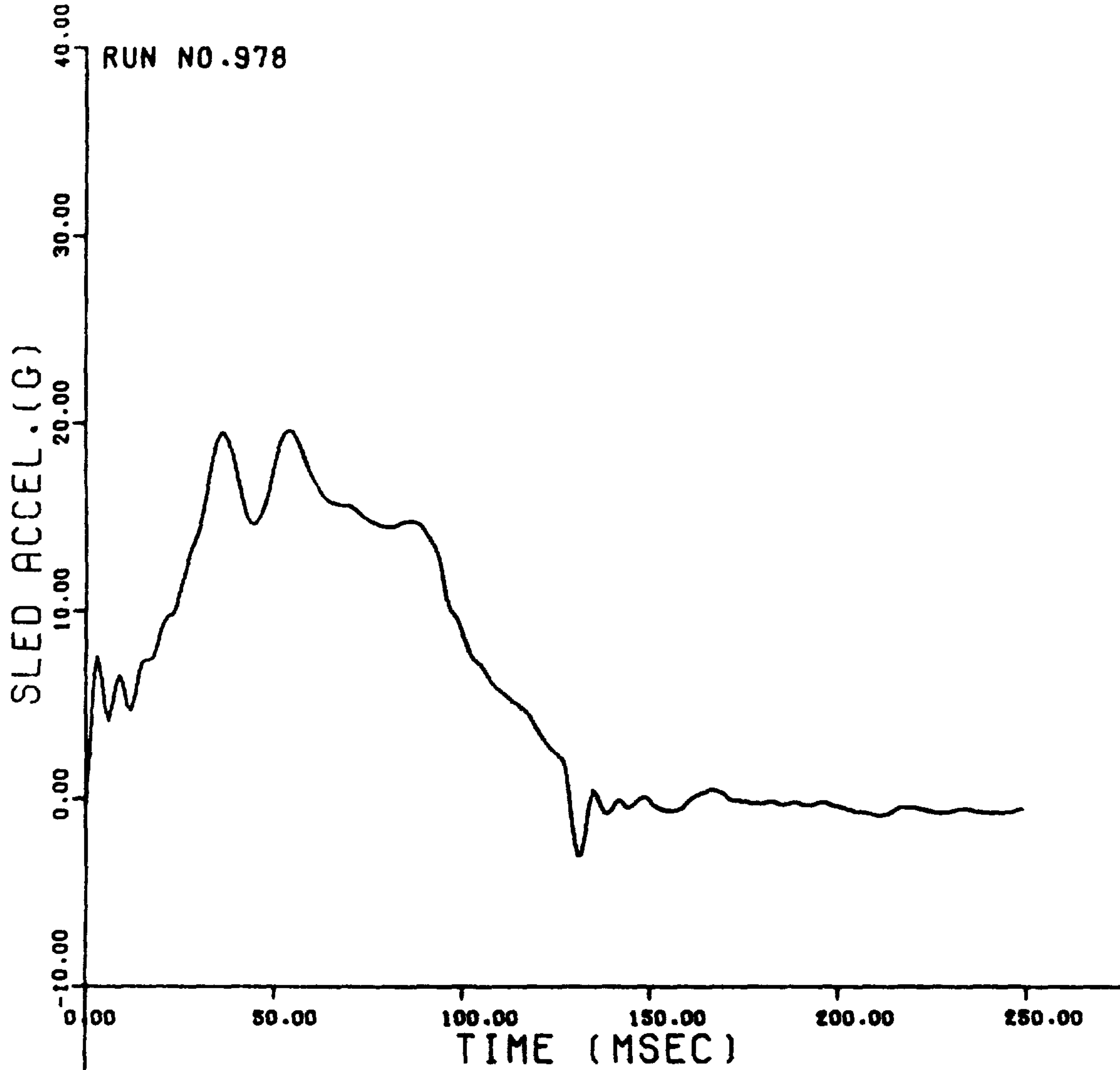
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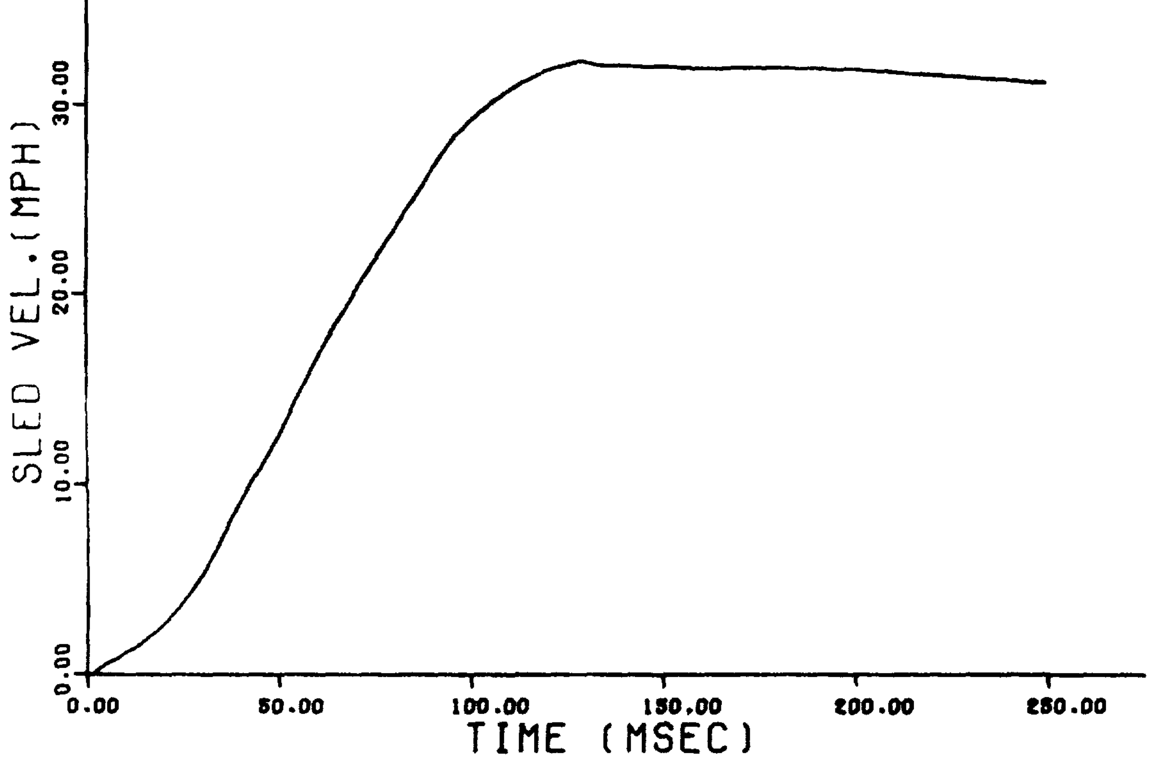
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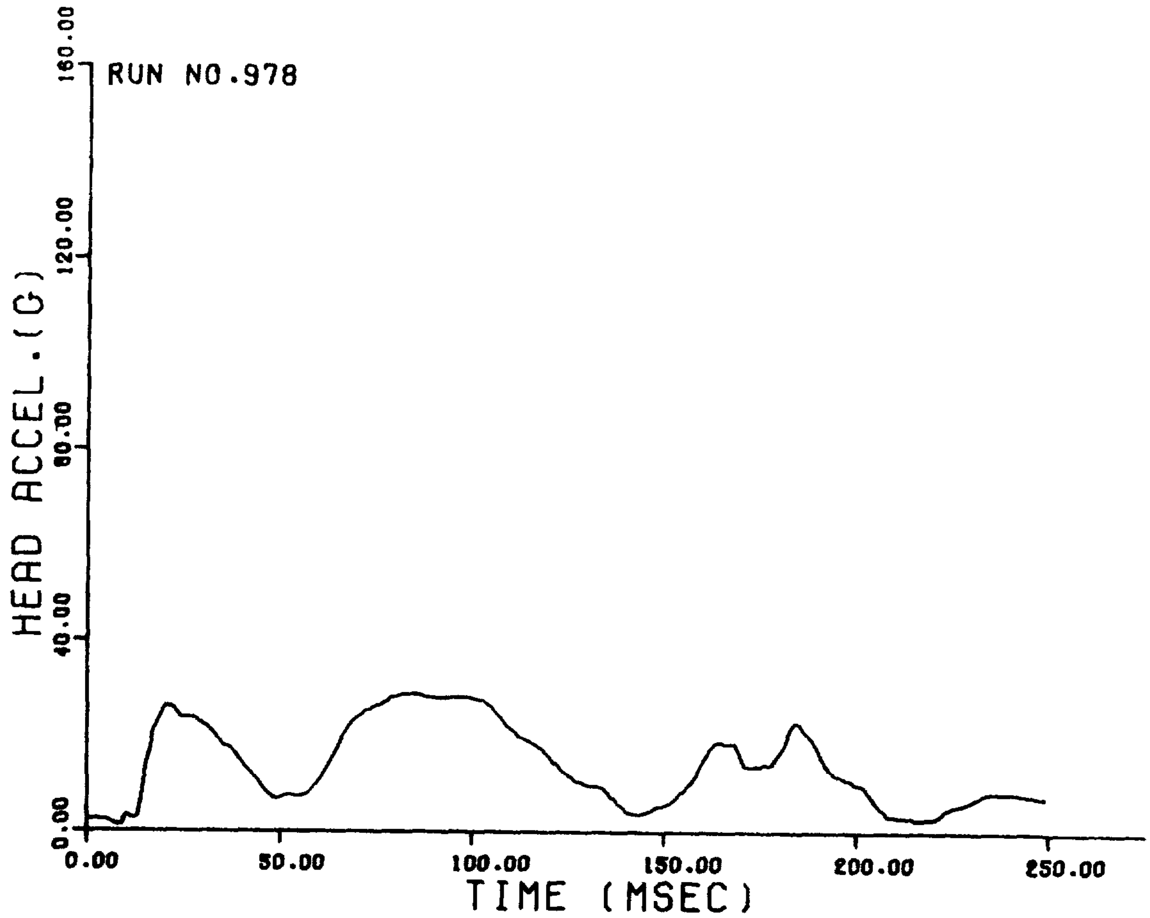
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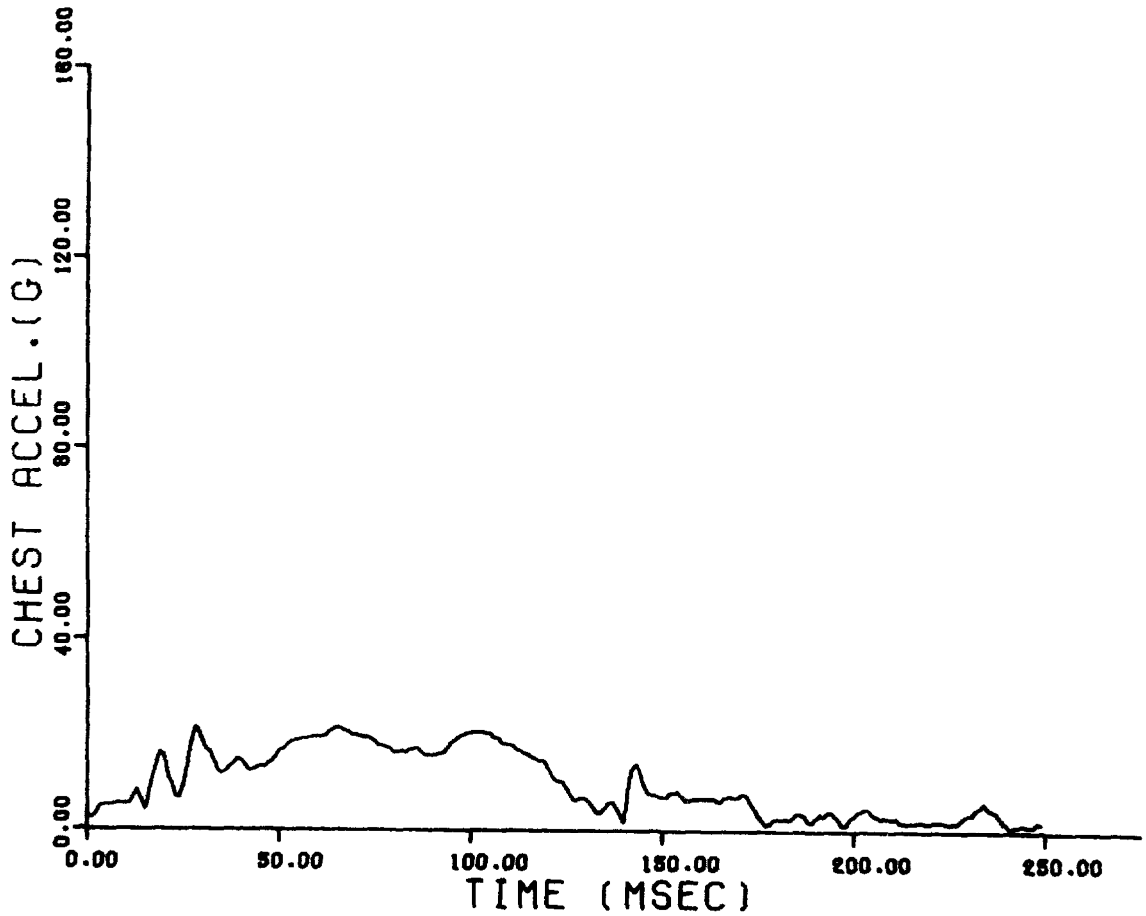
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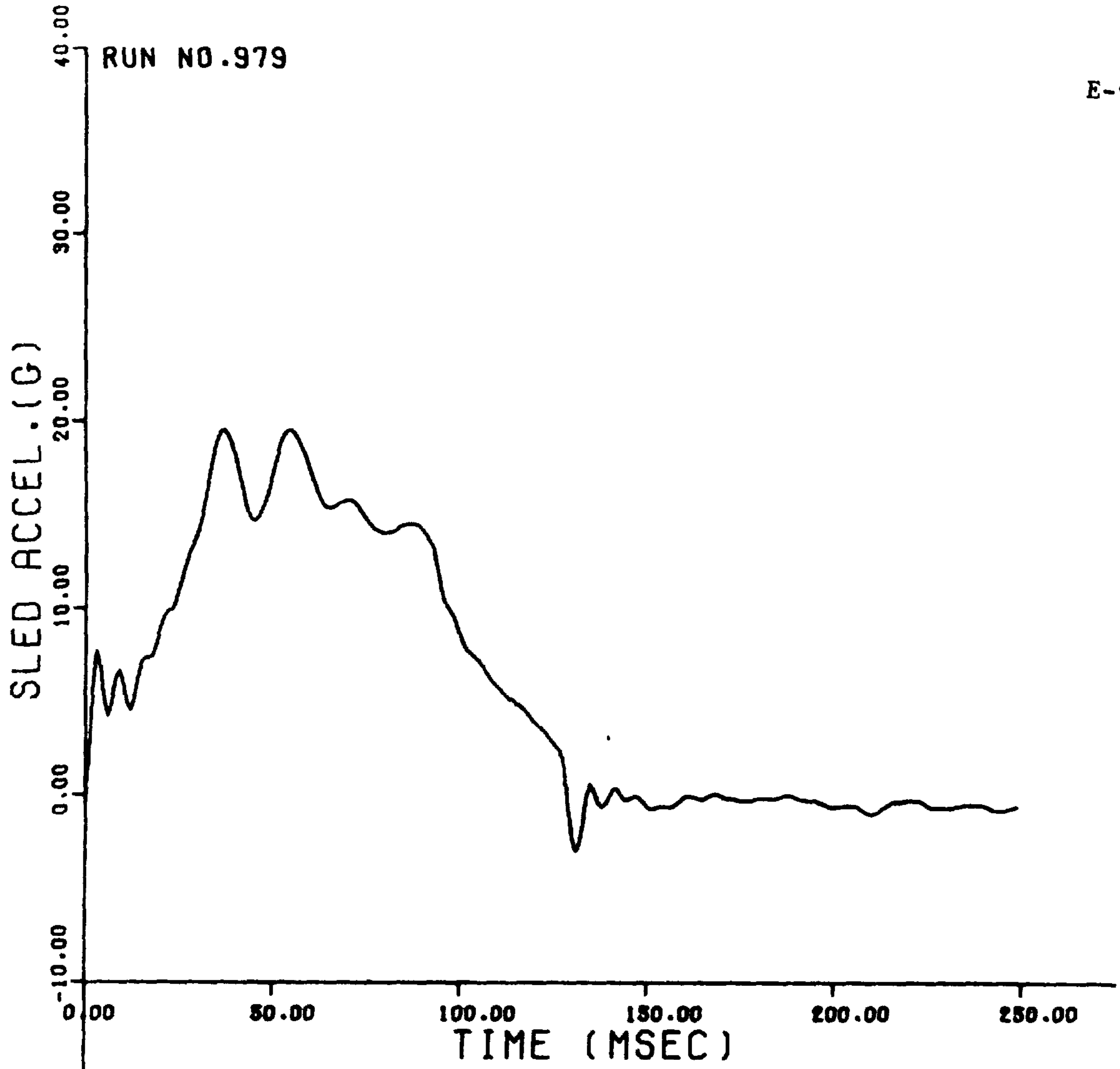
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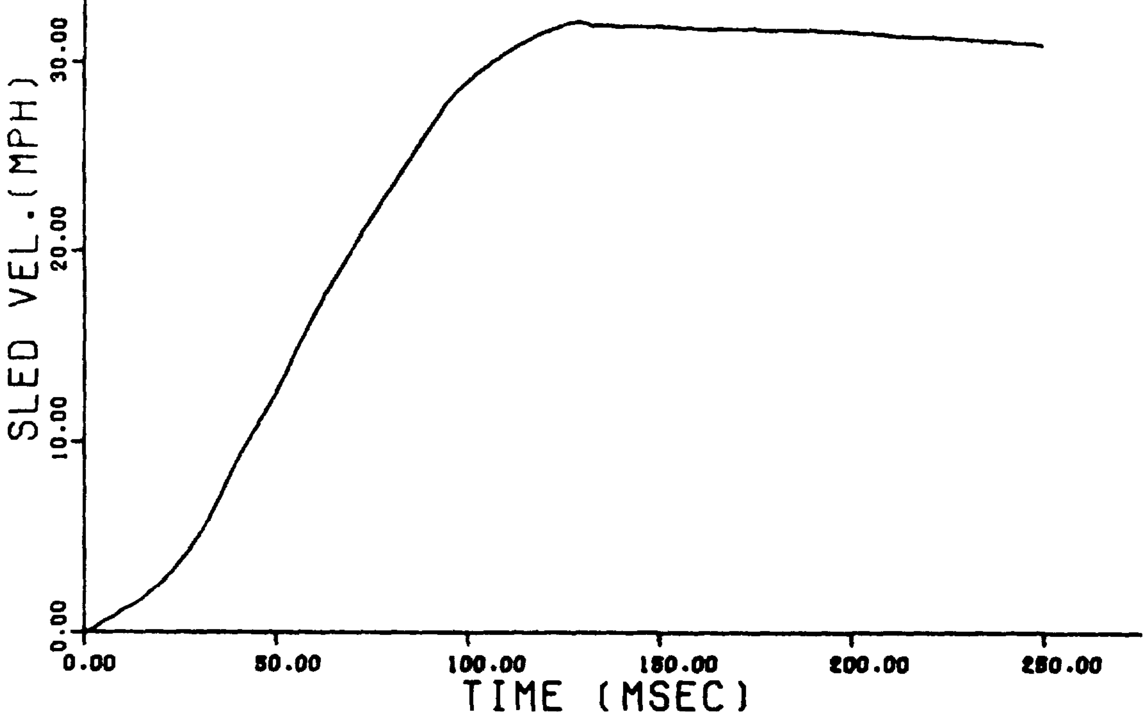
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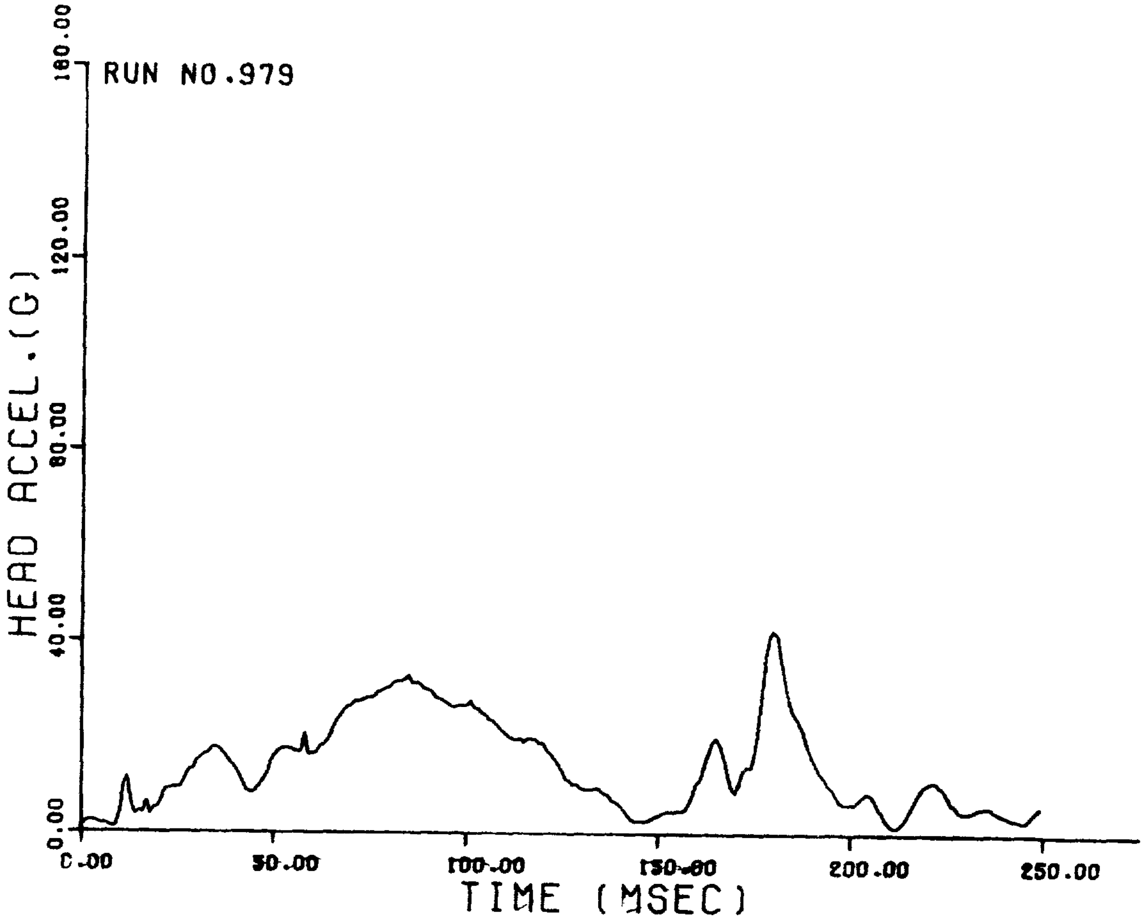
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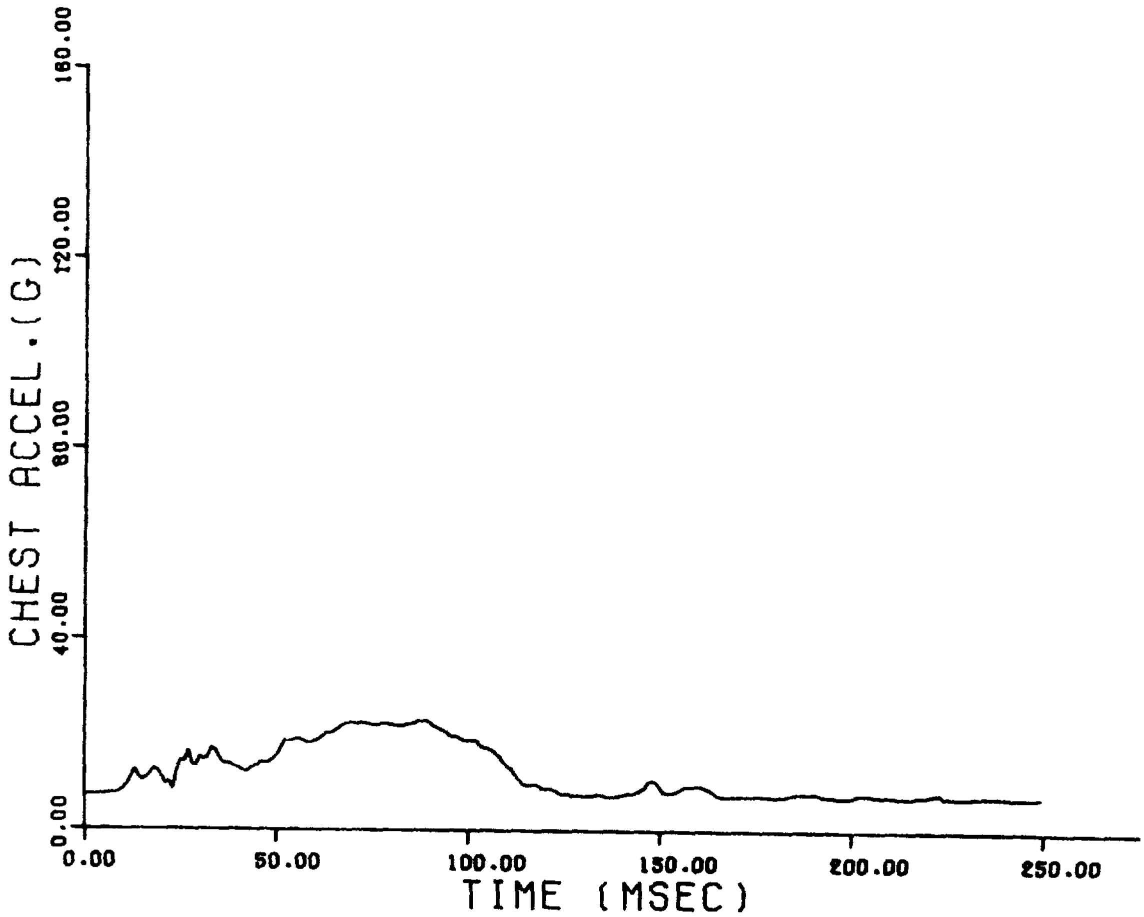
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